



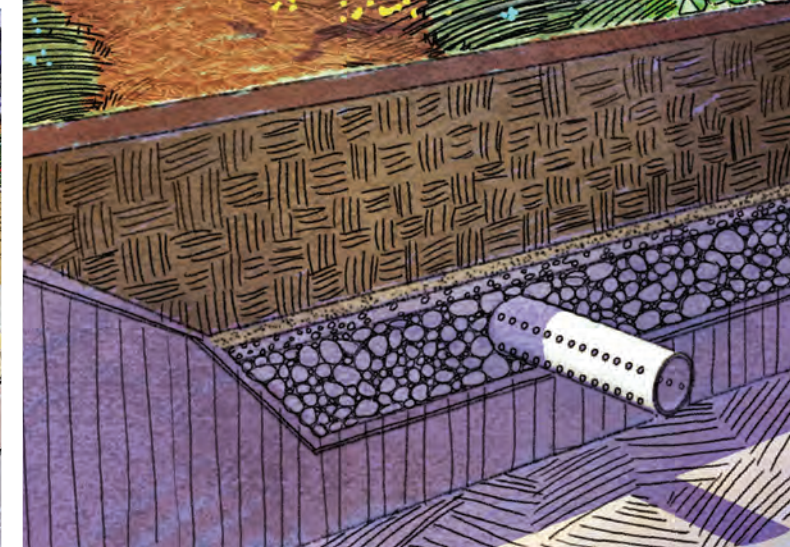
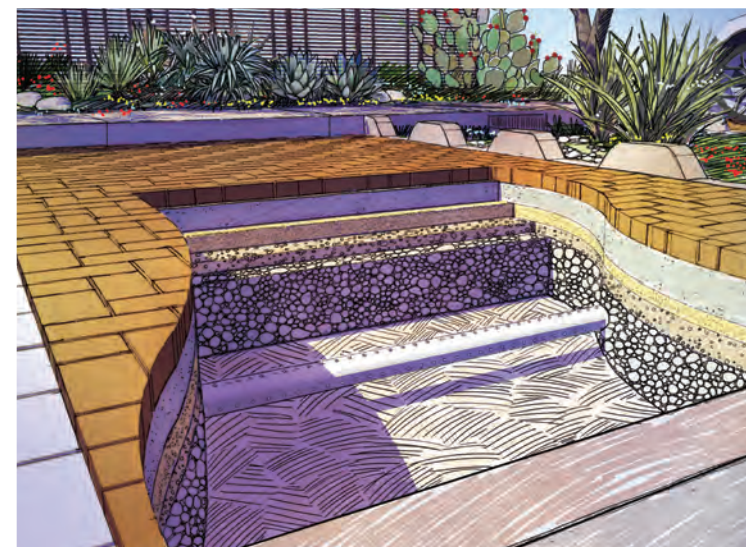
SAN ANTONIO RIVER BASIN LOW IMPACT DEVELOPMENT
TECHNICAL DESIGN GUIDANCE MANUAL
SECOND EDITION • MAY 2019



SAN ANTONIO
RIVER AUTHORITY

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SAN ANTONIO
RIVER AUTHORITY

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Foreword

The San Antonio River Authority (SARA) is leading activities within the San Antonio River Basin to promote sustainable land use. These efforts work towards preserving natural watershed functions that manage the quality and quantity of stormwater runoff through a balance of economic, environmental, and quality of life considerations.

As with most other watersheds in the United States, development within the San Antonio River Basin has modified the natural function of the basin. In the San Antonio River Basin, infrastructure has been built to direct stormwater runoff into nearby rivers and creeks. SARA water quality monitoring data indicates that pollutants carried by stormwater runoff are the greatest threat to creek and river health. During storm events, rainwater runoff picks up bacteria, oils, hydrocarbons, sediment, fertilizers and other contaminants from yards, fields, sidewalks, parking lots and streets and deposits these contaminants into our creeks and rivers. This is especially problematic in urban areas during small rain events, where the high concentration of “first flush” pollutants can reduce a creek’s dissolved oxygen, resulting in fish kills and building concentrations of other contaminants in a creek bed’s sediment.

Ensuring the sustainability of our rivers and creeks and the bays and estuaries into which they flow involves reducing direct runoff and capitalizing on the land’s natural ability to filter pollutants. Low Impact Development (LID) is a stormwater management strategy that works to replicate the predevelopment hydrologic processes and reduce the harmful impacts of urban runoff. LID techniques have been shown to improve water quality, reduce localized flooding and, when incorporated into a project’s design early in the process, reduce overall costs.

Multiple regional partners have established goals for improving the sustainability of the San Antonio River Basin’s watersheds. The Bexar Regional Watershed Management (BRWM) partnership seeks, through a committee process, to address water quality issues collaboratively and to provide public information and education about water quality issues. Additionally, the SA2020 community vision plan initiated by Mayor Julián Castro has established performance metrics for stewardship of the area’s natural resources and encourages development practices that are focused on Smart Growth, LID and Green Building.

To meet this need, the BRWM’s Low Impact Development Manual Technical Subcommittee worked collaboratively with SARA to develop the San Antonio River Basin Low Impact Development Technical Design Guidance Manual. The subcommittee started with the premise that a manual is a necessary step for educating the professional community on the strategies and standard practices for stormwater management LID techniques. This collaborative effort brought together governmental, technical, design, business and advocacy interests to develop the goals and content of the manual. This extensive process provided a forum for engineers, architects, landscape architects, resource managers, scientists, policy and planning managers, vendors and designers to provide ideas for the development of the manual, as well as review of its content.

This manual is intended to be used by the communities in the San Antonio River Basin to plan and design stormwater best management practices (BMPs). It provides guidance on the proper selection, design, inspection and maintenance of LID BMPs. The overarching goal is to provide clear, unambiguous design guidance that is customized to the unique land formation and soil conditions in the San Antonio region.

Prepared in Cooperation with:



Partners combining resources to improve flood control and water quality.



The development of this manual has benefitted from the input and review of the following participants, and SARA wishes to thank them for their efforts, time and expertise:

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San Antonio River Basin

Low Impact Development Technical Design Guidance Manual

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Acronyms and Abbreviations

%	percent
°F	degrees Fahrenheit
ADA	Americans with Disabilities Act
ADV	Acoustic Doppler Velocimeter
ASTM	American Society for Testing and Materials
BMPs	best management practices
BOD	biochemical oxygen demand
BRWM	Bexar Regional Watershed Management
C	rational method coefficient
CEC	cation exchange capacity
CIPs	capital improvement projects
CO ₂	carbon dioxide
COSA	City of San Antonio
ETJ	extraterritorial jurisdiction
FILO	fee in lieu of
ft ²	square feet
GI	Green Infrastructure
hr	hour
HSG	hydrologic soil groups
HSPF	Hydrologic Simulation Program in Fortran
IMPLND	impervious land
in	inch
IPM	integrated pest management
IWS	internal water storage zone
LID	low impact development

LOMC	letter of map change
meq	milliequivalents
mg/L	milligrams per liter
mm	millimeter
MS4	Municipal Separate Storm Sewer System
NCDC	National Climatic Data Center
NO ₂	nitrogen dioxide
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
O ₃	ozone
O&M	operation and maintenance
OSHA	Occupational Safety and Health Administration
P.E.	professional engineer
PM-10	particulate matter that is 10 µm or smaller
ppm	parts per million
PVC	polyvinyl chloride
QAPP	quality assurance project plan
s	second
SARA	San Antonio River Authority
SAWS	San Antonio Water System
sec	second
SO ₂	sulfur dioxide
SUSTAIN	System for Urban Stormwater Treatment and Analysis IntegratioN
SWMP	stormwater management plan
SWPPP	stormwater pollution prevention plan
T _c	time of concentration
TCEQ	Texas Commission on Environmental Quality
TGM	Edwards Aquifer Rules—Technical Guidance on Best Management Practices
TKN	total Kjeldahl nitrogen
TMDLs	total maximum daily loads
TSS	total suspended solids
TxDOT	Texas Department of Transportation
UDC	Unified Development Code
U.S. EPA	U.S. Environmental Protection Agency
VFS	vegetated filter strip
VS	vegetated swale
WDM	Watershed Data Management
yrs	years
µ	micro (one millionth or 10 ⁻⁶)

1. Introduction

1.1 Purpose of the Manual

Land development and urbanization alter and inhibit the natural hydrologic processes of surface water runoff patterns, infiltration, percolation to ground water, and evapotranspiration. Under predevelopment conditions, up to half of the annual rainfall infiltrates through the sandy soils and percolates downward where portions of it can recharge the ground water or provide base flow to streams (USEPA 2005). In contrast, developed areas can generate up to five times the annual runoff and allow one-third the infiltration of natural areas (FISRWG 1998, USEPA 2005). This change leads to increased erosion, reduced ground water recharge, diminished base flow in streams, increased stream flows during storm events, and degraded water quality.

Traditional engineering approaches to stormwater management convey runoff rapidly from developed surfaces into drainage systems, discharging large volumes of stormwater and pollutants to downstream receiving waters. As a result, stormwater runoff from developed land is a significant source of many water quality, stream morphology, and ecological impairments (USEPA 1999).

Reducing the overall imperviousness and using the natural drainage features of a site are important design strategies to maintain or enhance the site's hydrologic characteristics after development. This can be achieved by applying Low Impact Development (LID) stormwater management strategies. LID, which works to replicate predevelopment, natural hydrologic processes and reduce the disruptive effects of urban development on runoff patterns, has emerged as an alternative stormwater management approach that is complementary to conventional stormwater management measures including stormwater *best management practices (BMPs)*.

LID strategies are structural stormwater BMPs and planning techniques that are intended to reproduce predevelopment hydrologic conditions by reducing impervious surfaces and infiltrating, evaporating, and storing stormwater runoff using native or improved soils, vegetation, and bioengineering. Unlike the conventional method of quickly discharging stormwater off-site and conveying it to a downstream watershed, LID treats stormwater as a resource on-site. Site assessment, site planning, and on-site stormwater management guide the initial design phases of a project to maintain a more hydrologically functional landscape even in denser urban settings.

The San Antonio River Authority (SARA) and its Bexar Regional Watershed Management (BRWM) partners have developed this design manual to proactively address water quality and water resource protection in the San Antonio River Basin while building a sustainable community that balances these environmental concerns with economic and quality of life benefits. This manual is intended to provide property owners, reviewers, designers, policymakers, citizens of the San Antonio River watershed, and other stakeholders with a common understanding of LID goals, objectives, and specifications for individual BMPs. The LID practitioner can use this manual to evaluate the applicability of LID BMPs to a site, perform site assessment and planning, and design BMPs appropriate to specific site conditions. The best, most applicable techniques for the San Antonio region are included in this manual, and design details have been created to fit local preferences on the basis of input from the BRWM LID Subcommittee. Other LID BMP options exist; however, the BRWM LID Subcommittee chose to focus on the nine original BMPs presented

in this manual, with the extended detention basin being added for the current reissue based upon stakeholder requests.

This manual is intended to provide sufficient instruction and technical resources to help properly plan, select, design, and maintain LID BMPs. To accomplish this, the manual provides a balance of detailed technical information with clearly described step-by-step site assessment, planning, layout, selection, and BMP design instructions that complement existing or established hydraulic and hydrologic treatment standards. Before referencing this manual for guidance, users should first become familiar with the fundamental principles and regulatory drivers for LID in the opening and second chapters, respectively, as well as current stormwater standards governing stormwater runoff in the San Antonio River Basin (see Appendix G) to effectively use this manual to meet stormwater requirements.

1.2 Applicability of the Manual

This manual establishes design guidelines to meet local stormwater and water quality protection goals. It does not establish a legal standard for such functions and is not intended to do so. Moreover, the guidelines do not supersede requirements and policies established through adopted community plans, regional and city standard drawings, or other city council adopted policy or regulatory documents. Instead, the manual is intended to work in concert with those policies and regulations. The manual complements other acceptable methods used to meet existing stormwater management regulations, including those in the Edwards Aquifer Recharge and Transition Zones, and is applicable to private development and public infrastructure projects in cities and counties in the region. The guidance is applicable to newly developing areas and to older developments that are undergoing revitalization or redevelopment.

1.3 How to Use the Manual

The *San Antonio River Basin Low Impact Development Technical Design Guidance Manual* aids owners, designers, and caretakers in analyzing, planning, designing, constructing, maintaining, and monitoring LID projects from start to finish. The manual has five chapters and seven appendices, and the content is intended to be used by practitioners with knowledge of stormwater processes (Figure 1-1).

The Introduction ([Chapter 1](#)) provides the local context for LID implementation, a general description of LID, site design principles, and the benefits of LID. [Chapter 2](#): Regional Considerations describes regional geology and climate as well as the local regulatory framework when developing and implementing LID BMPs. LID Selection—Structural BMPs ([Chapter 3](#)) outlines unit-process-based design for selection and placement of LID BMPs, and Appendix B expands on these concepts by providing detailed design guidance. Construction considerations that can affect BMP design and implementation are included in [Chapter 4](#): Execution Considerations. Finally, [Chapter 5](#): LID Review Process provides guidance for reviewers who are tasked with evaluating LID designs and approaches for agencies that plan to allow LID implementation in their jurisdictions.

Seven supporting technical appendices are integral to the steps, processes, construction, and operation and maintenance of LID BMPs described in the main document. Appendix A: BMP Sizing and Example Calculations presents a tool for sizing LID BMPs. As mentioned, Appendix B: BMP-Specific Details for Design provides in-depth design guidance, including specifications,

Chapter 1: Introduction

considerations, and renderings. Appendix C: Design Examples and Templates includes design details for each type of LID practice, and Appendix D: BMP Design Fact Sheets presents a summary of design specifications for each BMP type. Appendix E: Plant List includes a list and attributes of plants that are well-suited for LID practices in San Antonio. Appendix F: Facility Inspection and Maintenance Checklist is a tool for practitioner’s use to help ensure that each facility is designed, installed, and maintained correctly. Appendix G: Cost Estimates and Regulatory guidance provides planning level cost estimates for implementation and annual estimates for operation and maintenance along with an overview of regulations that impact LID implementation for each jurisdiction in the San Antonio River Basin.

Organization of the Manual

Chapter 1: Introduction provides the general background and need for implementing LID practices. It also provides step-by-step instructions for site assessment, planning, and preliminary layout of LID BMPs.

Chapter 2: Regional Considerations discusses local ecology, geology, and climate factors relevant to LID design. It includes a discussion of federal, state, regional, and local regulation applicable to stormwater management and LID implementation.

Chapter 3: LID Selection—Structural BMPs includes a summary description of all recommended LID BMPs and instructions for selecting site-appropriate BMPs.

Chapter 4: Execution Considerations summarizes implementation considerations, including operation and maintenance needs and cost-reduction measures.

Chapter 5: LID Review Process gives guidance for reviewers who are tasked with evaluating LID designs and approaches for entities that plan to implement LID in their jurisdictions.

Appendix A: BMP Sizing that is based on site conditions and local rainfall information, including instructions for using a tool that assists with sizing LID BMPs and a description of the tool's development.

Appendix B: BMP Design Guidance provides design specifications, considerations, and helpful renderings of what a system might look like once built. Also provided are real-world renderings of design adaptations.

Appendix C: BMP Design Templates includes one-page examples of design details for individual BMP applications. Electronic files are also available for download from the San Antonio River Authority website, in AutoCAD format, for incorporation into construction drawings.

Appendix D: Fact Sheets contains design fact sheets for all LID BMPs included in the manual. The fact sheets are intended to be a one-page summary of key BMP design, construction, and maintenance considerations.

Appendix E: Plant List includes a detailed plant list, specific to the San Antonio region, to help with LID BMP design.

Appendix F: Inspection and Maintenance Checklist provides a facility inspection and maintenance checklist for LID BMPs with checklists combined, in the case of multiple BMPs used together as a treatment train.

Appendix G: Cost Estimates and Regulatory Guidance includes planning-level cost estimates for each BMP type and a summary of relevant regulations for the jurisdictions in the San Antonio River Basin.

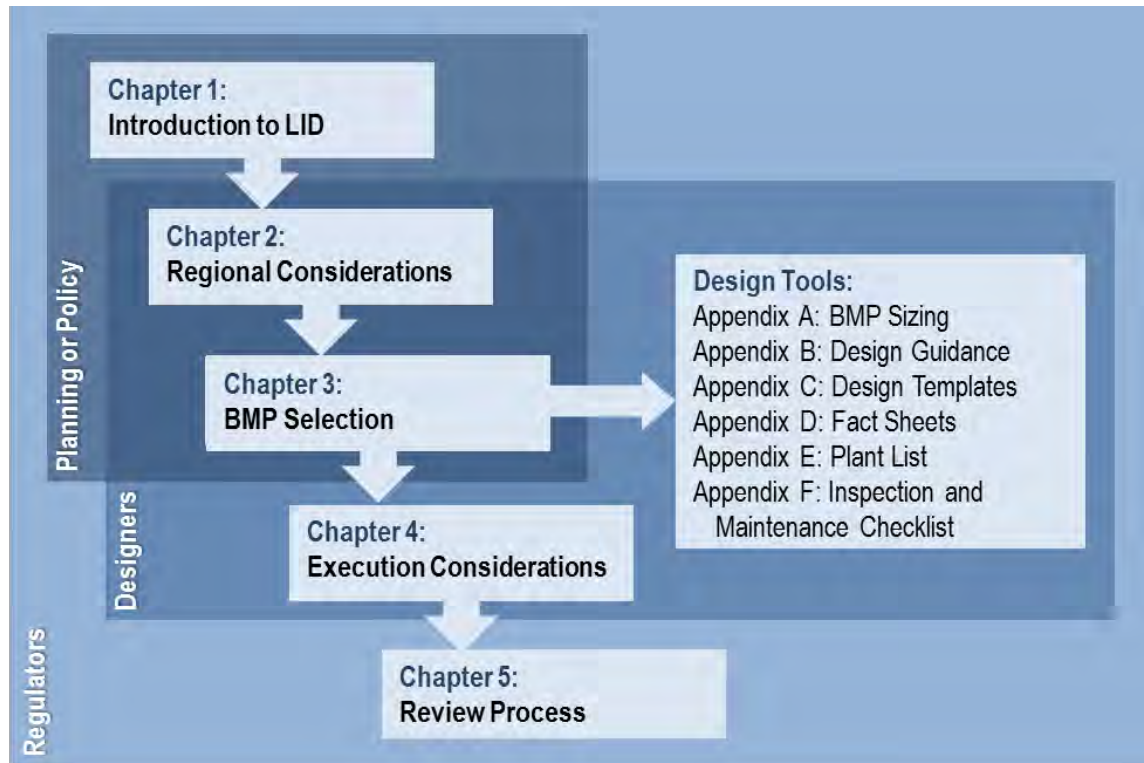


Figure 1-1. Document organization and intended users

As a design team¹ develops a greater understanding of LID principles and becomes more experienced in designing BMPs, use of this manual can be further simplified by relying on the templates and fact sheets in Appendix C and Appendix D. Designers familiar with the design process could choose to reference the one-page fact sheets during the design process to remind themselves of key assumptions and design recommendations.

1.4 Background

In natural, undeveloped landscapes, the hydrologic processes of infiltration of surface water into the ground (both near surface and deep percolation), evaporation, and transpiration work to recycle rainwater through plants and soil minimizing the transfer of pollutants to surface and ground waters (Figure 1-2). As land development and urbanization occur, natural or vegetated areas are replaced with streets, parking lots, buildings, and compacted soils. Such impervious surfaces modify the natural hydrology, decrease the permeability of the landscape, and dramatically affect the natural hydrologic cycle.

Stormwater runoff from increased impervious surfaces in urban areas has emerged as a significant threat to water quality.

Source: USEPA 2004

¹ LID works best when incorporated into projects early in the design stage by an integrated, multi-disciplinary team consisting of architects, engineers, and landscape architects.

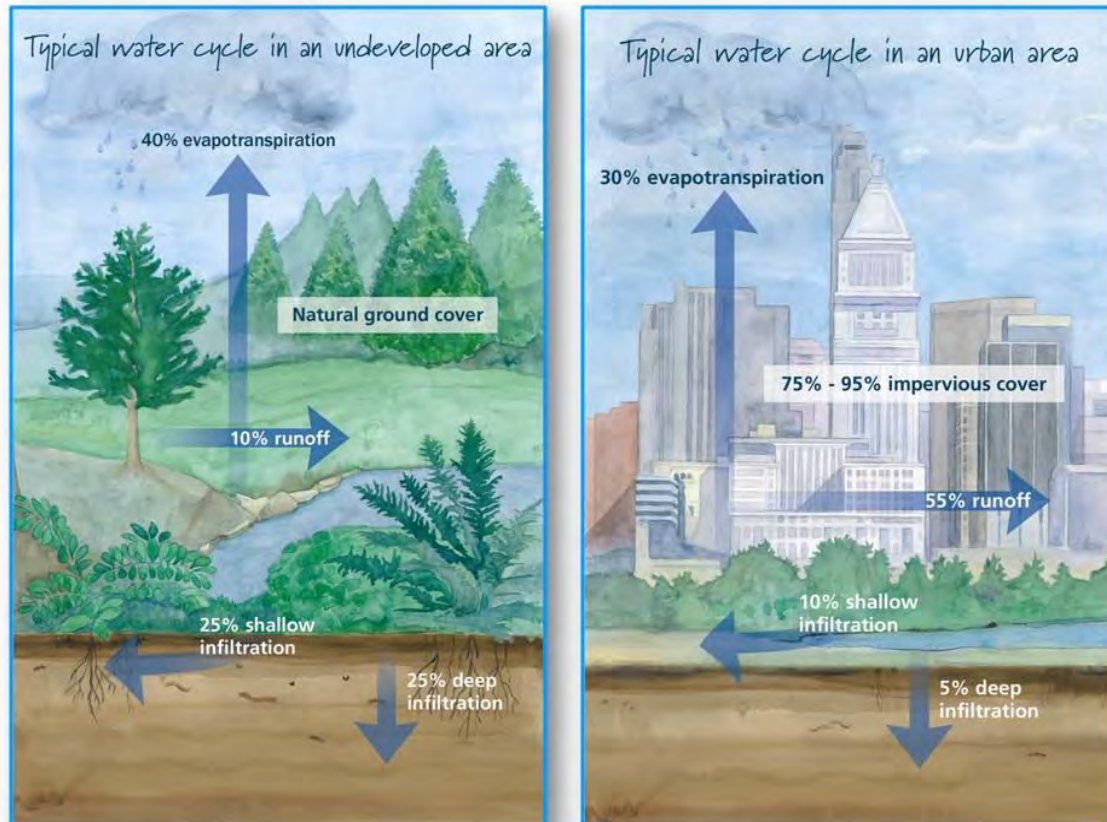


Figure 1-2. Typical water cycle in an undeveloped area versus an urban setting (adapted from FISRWG 1998, USEPA 2005).

Depression storage, infiltration, percolation (deep infiltration), and interception (the capture of water by vegetation before reaching the ground) all decrease as a natural site is developed with higher impervious cover. Impervious areas and compacted soils reduce infiltration, which creates increased overland runoff and shorter times of concentration that can have cascading effects throughout the watershed. The impact of imperviousness can include increases in annual runoff volumes, increased peak discharges, increased pollutant loads, increased frequency and magnitude of flooding, stream habitat degradation, and diminished stream base flows (CWP 2004).

The amount of impervious cover in a watershed has been identified as a common factor in watersheds with stream degradation (Prince George's County 1999), and significant declines in the biological integrity or physical habitat of a stream have been found in watersheds with as little as 10 percent imperviousness (Schueler 1994). With decreased percolation of infiltrated runoff, shallow ground water recharge rates to streams and surface waters (interflow) are reduced. In turn, this reduces the amount of base flow in the surface waters, which can noticeably alter the physical habitat conditions of streams or shoreline areas. Both reduced infiltration rates and high-velocity surface flows can lead to increased surface erosion and gully formation. These processes ultimately destabilize stream banks and often wash sediment into surface waters. Finally, decreased infiltration leads to greater stormwater volumes and longer durations of peak flows. Energy generated by the increased peak volumes is further compounded as flows are directed into

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conveyance systems that slope toward surface waters, increasing flow velocity. Once discharged to surface waters, the energized flow can erode streambeds and banks (USEPA 2005; MacRae 1996). Ultimately, these erosive flows to surface waters can dramatically degrade water quality and significantly affect aquatic ecosystems.

Historically, the goal of urban drainage infrastructure was to convey water quickly away from a developed site to prevent localized flooding. Such conveyance systems were engineered to direct flows from impervious surfaces (e.g., streets, parking lots, sidewalks, and buildings) to curbs, gutters, storm drains, and, ultimately, to surface waters such as streams and rivers. Therefore, these conveyance systems carry runoff and pollutants from developed areas directly into the receiving waters. Urban runoff is considered among the most significant threats affecting the nation's waterways (USEPA 2004). Pollutants commonly associated with urban runoff are sediment, trash, organic matter, nutrients (particularly phosphorus and nitrogen), hydrocarbons such as gasoline and oil, pesticides/herbicides, fertilizers, metals, and pathogens associated with fecal waste.

Later approaches to stormwater management focused on peak flow control (e.g., extended detention), which provided flood control and some water quality benefits but did little to protect headwater streams or address the total volume of runoff entering receiving waters. In recent years, LID has been tested and shown to be successful in a variety of settings both nationally and internationally and has risen to the forefront of stormwater management approaches.

Functioning as a first line of defense against the negative impacts of excess stormwater, LID is a fundamentally different approach from traditional stormwater management. LID aims to manage stormwater at the site, often including some form of treatment and volume control for smaller storm events. Treating stormwater at the site minimizes the volume that is washed overland and into traditional conveyance systems. Minimizing such volumes reduces pollutants washed into surface waters and can result in significant water quality improvement (USEPA 2009) and reduce exposure to flood hazards (Medina et al. 2011).

LID practices offer an innovative way to integrate stormwater management into natural landscapes, minimizing alterations to the natural hydrologic regime and reducing the volume of site runoff (Figure 1-3). Implementing LID practices can enhance water quality treatment, encourage ground water recharge, and reduce soil erosion and pollutant transport. Additional benefits of LID implementation are the potential to use LID practices to enhance improved greenways and park lands, enrich natural environmental aesthetics in urban settings (Figure 1-4) and reduce the need for traditional drainage infrastructure (see [Section 1.7](#) for an expanded discussion of the multiple benefits of LID). These concepts are of great interest in areas with high quality aquatic recreation or aquatic life habitats and can effectively complement ongoing efforts to improve the San Antonio River and its tributaries.

Offering considerable versatility with design and implementation, LID concepts can be incorporated into new and existing developments and can, in some cases, be less costly than traditional, structural stormwater management systems (USEPA 2007, 2012a). It is important to integrate LID BMPs with other on-site drainage that can safely convey flows from larger storms to downstream systems or streams.



Figure 1-3. LID incorporated into traditional parking lot design



Figure 1-4. A bioretention area provides attractive landscaping that is also functional, Portland, Oregon. Source: Tetra Tech

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LID implementation and associated benefits can be considered at three scales—the site or block scale, the community or neighborhood scale, and the regional or large watershed scale. Because the influences of urbanization are evident at all three scales, individual LID BMPs can mitigate the negative effects of urban runoff at the site and neighborhood scales as well as the watershed as a whole.

At the watershed scale, decisions on where and how to develop are critical to water quality and natural resource protection. In San Antonio, citizens and the collective community have chosen to influence growth patterns over the Edwards Aquifer Recharge and Contributing Zones. Growth, development, and redevelopment offer resources and opportunities to revitalize a downtown, refurbish streets, build new schools, and develop diverse places to live, work, shop, and play. Growth creates challenges for communities striving to protect or restore their natural resources. Development approaches must be transformed to use land efficiently and protect sensitive natural and cultural areas while treating water as a resource that can be used on-site or recharged for extended use as base flow or water supply. Smart growth and LID principles are important tools to incorporate into planning and zoning to achieve multiple environmental, community, and aesthetic benefits throughout the watershed. Once local governments have assessed the best placement for growth and preservation in a watershed, many LID practices can be applied at the community or neighborhood scale. These community-scale techniques, such as reducing road widths, replacing curb and gutter with roadside swales, and refocusing development practices, necessarily extend beyond individual development sites and can be applied throughout a neighborhood.

Finally, site-specific stormwater strategies, such as rain gardens, green roofs, stormwater capture, or disconnected downspouts and impervious areas, are integrated in each development or parcel of land to benefit the whole community. Many LID practices can be applied at all three scales. For example, opportunities to maximize infiltration occur in all scale categories. Likewise, all LID practices strive to decrease the overall amount of effective impervious cover. Some approaches used to minimize impervious cover and maximize infiltration are

- Minimizing land clearing and disturbance
- Clustering buildings
- Encouraging development on already affected land (e.g., vacant urban lots)
- Using narrower roads, designing smaller parking lots, and co-locating uses that have different peak traffic times
- Using permeable pavement
- Encouraging mixed use developments that encourage residents to walk rather than drive
- Designing more compact residential lots with shared common open space (Conservation Development under the City of San Antonio Unified Development Code, for example, requires 40% open space.)
- Increasing residential unit densities through vertical building or zero lot lines and preserving more open space.

These principles, implemented within a sound regulatory approach, improve livability and meet community goals for environmental sustainability while sometimes reducing development cost. This design guidance manual is a resource to proactively address water quality and water resource protection in the San Antonio River Basin while building a sustainable community that promotes improved health and quality of life.

1.5 Site Design Principles and LID

LID practices use natural features to slow and filter stormwater runoff. Project characteristics will define which LID BMPs are applicable. When determining the appropriate LID requirements, project managers must consider characteristics such as site location, existing topography and soils, and planning elements. These characteristics and their impacts on design are important because LID BMPs are permanent features that can affect other project elements; therefore, it is critical to conduct thorough site assessments to avoid the need for redesign later. Incorporating LID early in the site design stage could reduce the need for and cost of traditional drainage infrastructure by reducing the amount of stormwater to be conveyed off-site.

The following are the fundamental planning concepts of LID (Prince George's County 1999):

1. *Using hydrology as the integrating framework*

Integrating hydrology during site planning begins with identifying sensitive areas, including streams, floodplains, wetlands, steep slopes, highly permeable soils, and woodland conservation zones. Through that process, the development envelope—the total site area that affects the hydrology—is defined. This effort must include evaluating both upstream and downstream flow paths and drainage areas that may be affected.

2. *Use distributed practices*

Distributed control of stormwater throughout the site can be accomplished by applying small-scale LID BMPs throughout the site (e.g., bioretention in landscaped areas, permeable pavement parking stalls). This may include preserving areas that are naturally suited to stormwater infiltration and require little or no engineering. Such small-scale, LID BMPs foster opportunities to maintain the natural hydrology, provide a much greater range of control practices, allow control practices to be integrated into landscape design and natural features of the site, reduce site development and long-term maintenance costs, and provide redundancy if one technique fails.

3. *Controlling stormwater at the source*

Undeveloped sites possess natural stormwater mitigation functions such as interception, depression storage, and infiltration. Those hydrologic functions should be restored or

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designed as close as possible to the disturbed area (e.g. parking lot, building) to minimize and then mitigate the hydrologic effects of site development. Bioretention cells, as shown in Figure 1-5, are an example LID practice that can serve this function.

4. *Using simple, non-engineered methods*

Methods employing existing soils, native vegetation, and natural drainage features can be integrated into LID designs. These designs integrate natural elements into stormwater management and limit structural material including concrete troughs and vault systems. Examples include bioretention cells, curb pop-outs, and depressed medians, as shown in Figure 1-6.

5. *Creating a multifunctional landscape*

Urban landscape features such as streets, sidewalks, parkways, and green spaces, can be designed to be multifunctional by incorporating detention, retention, and filtration functions, such as curb pop-outs, as shown in Figure 1-6.

Siting and selecting appropriate LID practices is an iterative process that requires comprehensive site planning with careful consideration of all nine steps detailed in this chapter. A site planner, landscape architect, or engineer can follow these steps in developing final site plans, as described in Figure 1-7. The steps are arranged on the basis of the anticipated design phases of site assessment, preliminary design, and final design (Phases I, II, and III, respectively).

A thorough site assessment is needed initially to identify the development envelope and minimize site alterations. The primary objective of the site assessment process is to identify limitations and development opportunities specific to LID. For example, development opportunities include available space, use of right-of-way as appropriate, and maximizing opportunities where properly infiltrating soils exist. Constraints or limitations that need to be factored into site planning when implementing LID practices include



Figure 1-5. Bioretention cell adjacent to roadway, Mission Reach Operations Center, San Antonio, Texas.



Figure 1-6. Bioretention curb pop-out, Portland, Oregon. Source: Tetra Tech

- Slow-infiltrating soils (typically clays).
- Soil contamination.
- Steep slopes.
- Adjacent foundations of structures.
- Wells.
- Shallow bedrock.
- High seasonal water table.

For both new development and redevelopment, in the preliminary site plan, the development envelope (construction limits) is delineated. Applicable zoning, land use, subdivision, local road design regulations, and other local requirements should be identified to the extent applicable at this stage (Step 1 above; see Appendix G for information on local requirements). To make the best and most optimal use of LID techniques on a site, a comprehensive site assessment must be completed that includes an evaluation of existing site topography, soils, vegetation, and hydrology including surface water and ground water features. High quality ecological resources (e.g., wildlife habitat, mature trees) should also be identified for conservation or protection. With such considerations, the site assessment phase provides the foundation for consideration of and proper planning around existing natural features and to retain or mimic the site's natural hydrologic functions (Steps 2 and 3).

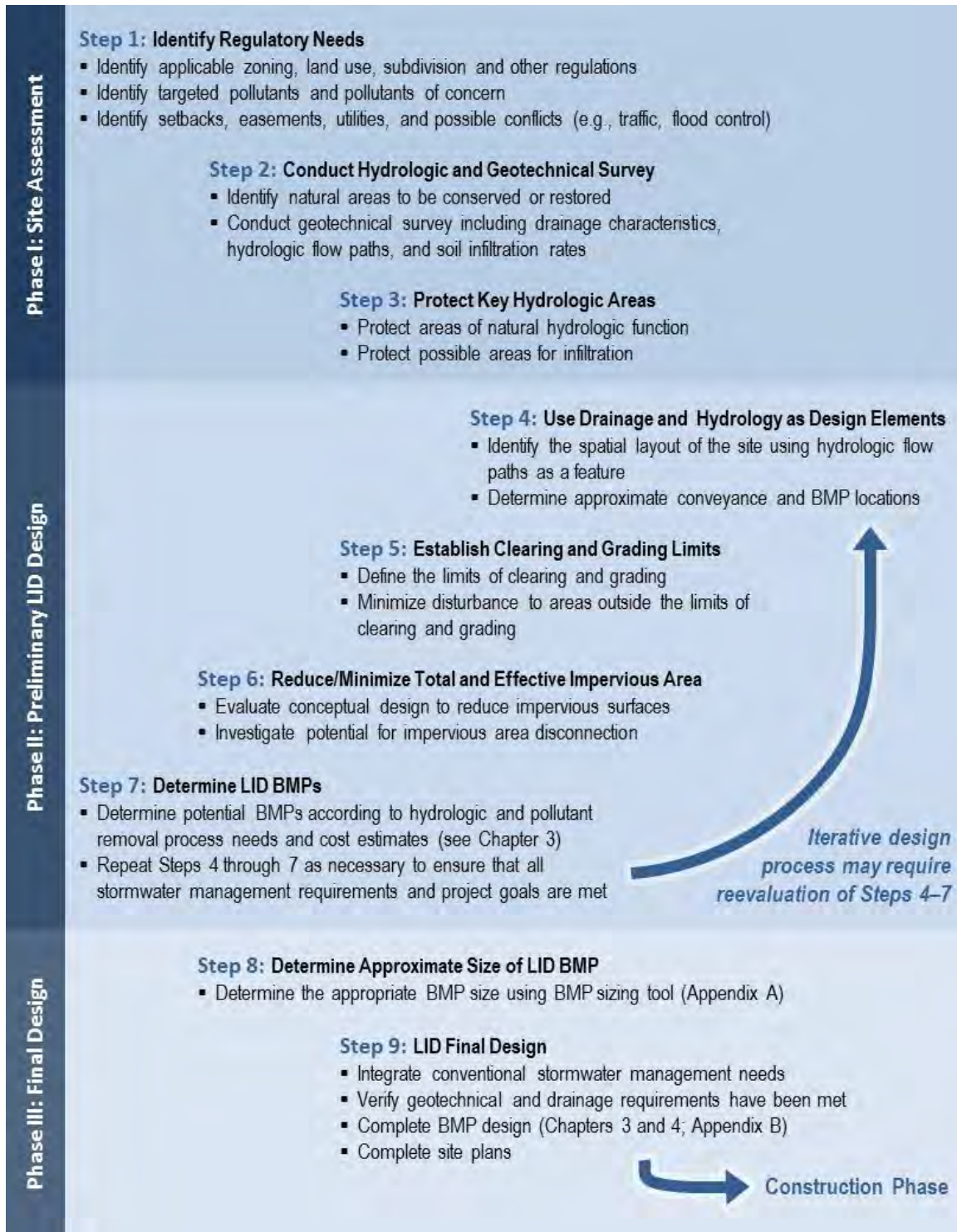


Figure 1-7. Steps to develop an LID-based site plan

Phase II, site planning, covers Steps 4–7. Defining preexisting and site-specific drainage patterns is essential for determining potential locations of LID BMPs (Step 4). Once natural and hydrologic features are identified and slated to be preserved, areas can be designated for clearing, grading, structures, and infrastructure (Step 5). After the preliminary site configuration has been determined

in light of the existing features, impervious area site plans (buildings, roadways, parking lots, sidewalks) can be evaluated for opportunities to minimize total impervious area in the site planning phase (Step 6). The specific types of LID BMPs are determined next (Step 7; e.g., a bioretention cell versus porous pavement for stormwater storage and infiltration).

In Phase III, final LID BMP footprints and sizes are estimated (Step 8; and for sizing, see Appendix A). An iterative process working between Steps 4 and 7 can help determine the final site layout for completing the design process (Step 9). These steps are presented in more detail in the following sections. When Step 6 is completed, detailed determination of stormwater management practice selection and design that considers BMP construction, and operation and maintenance (Chapters 3 and 4) should be made to complete Phase III and the final site design process. Steps 8 and 9 assist in determining BMP sizing and final design.

1.6 Example LID Conceptual Design

A series of conceptual site renderings, starting with Figure 1-8 below, demonstrate the phases of site assessment, preliminary design and planning through the final designs and shows how the site changes with each step. Figure 1-8 demonstrates a hypothetical site planned to include the construction of a new library, adjoining parking lot, and a surrounding park. This example site will be used to illustrate the steps described in the following sections.

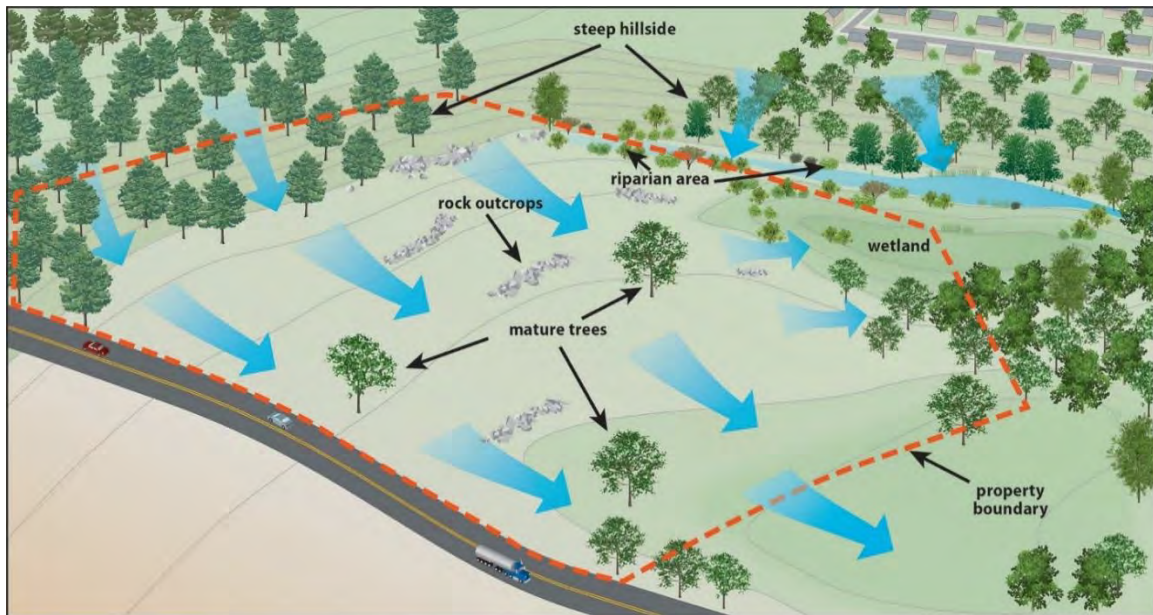


Figure 1-8. Example capital improvement project conceptual site for LID

1.6.1 Phase I—Site Assessment

The first phase of site planning is composed of the site assessment. Steps 1 through 3 below delineate the site assessment process.

Step 1: Identify Regulatory Needs

LID implementation must be consistent with the applicable federal, state, and local regulations; a general discussion of how the LID standards work with local regulations is in [Chapter 2](#) and Appendix G.

Identify applicable zoning, land use, subdivision, and other local regulations

Zoning ordinances and comprehensive planning by any local government entity (county, city, and such) provide a framework to establish a functional and visual relationship between growth and urbanization (Prince George’s County 1999). San Antonio’s zoning requirements are in Article III of the Unified Development Code. It is recommended that identified land uses also be shown in a visual format similar to Figure 1-9.

To Complete Step 1:

- Identify applicable zoning, land use, subdivision, and other regulations
- Identify setbacks, easements, and utilities (Call 811 for utility location)
- Identify targeted pollutants and pollutants of concern

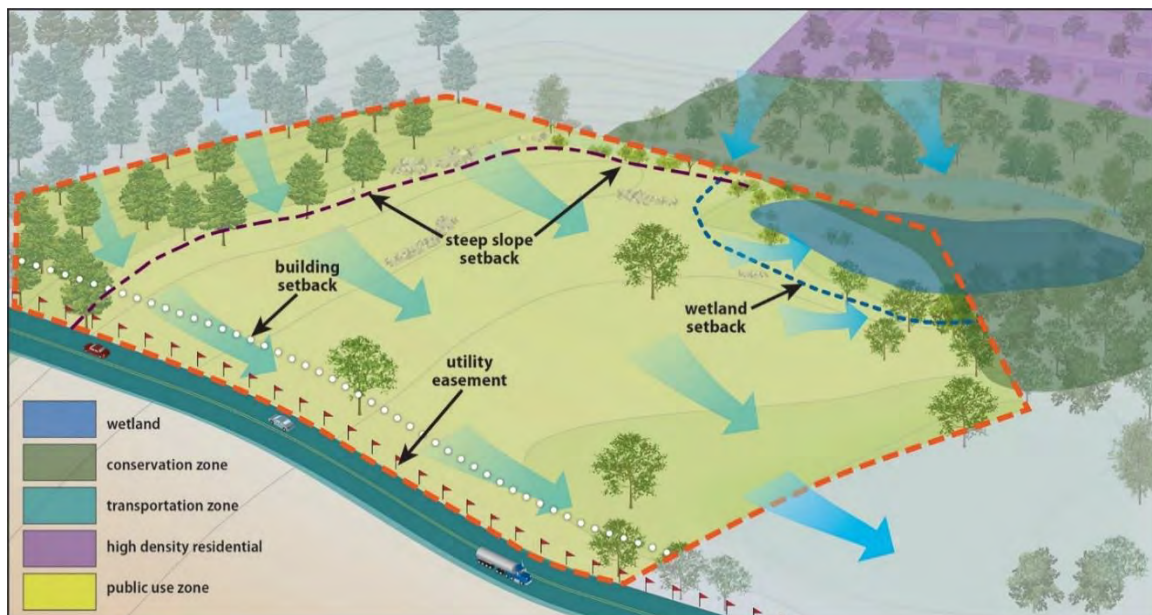


Figure 1-9. Identify applicable zoning requirements, utility easements, and site setbacks

Identify setbacks, easements, and utilities

Defining the boundaries of the site (yellow-dashed line indicating parcel boundaries) also includes identifying the required setbacks and any easements or utilities on the site. Municipal ordinances provide the basic regulations regarding the size and scale of development, such as permitted density, setbacks and structure height on the basis of the applicable zoning code (see Appendix G). Setbacks will restrict the buildable area. In addition to municipal ordinances, the Pollution

Prevention Criteria Sec. 34-913 of the SAWS Water Quality Ordinance requires buffers adjacent to streams in the recharge and contributing zones.

Planning and assessment must also include identifying easements on the site. Easements that could be present are a road or sidewalk (right-of-way) easement; a public utility easement that allows a utility to run gas, water, sewer or power lines through a private property; or a railway easement. Local utilities departments (e.g., electric, wastewater) should be consulted to determine whether utilities are above or below ground and the required distance that site disturbance should be maintained from any utilities present. Easements on a site can be determined by consulting as-built drawings and records research; these should be included on site drawings as illustrated by the row of flags in Figure 1-9.

Identify targeted pollutant and flow alteration needs

Section 30 of the Texas Administration Code (TAC) Chapter 213.5 includes a water quality performance standard that requires development in the Edward Aquifer Recharge or Transition Zone to design, construct, operate, and maintain permanent BMPs to remove 80 percent of the incremental increase in the annual mass loading of total suspended solids (TSS) from the site caused by the regulated activity. This Chapter also requires any development with more than 20 percent impervious cover to implement permanent BMPs. Those sites with less than 20 percent impervious are subject to local regulations that presently do not include water quality treatment for small storms.

The Texas Commission on Environmental Quality identifies impaired water bodies in the state that warrant attention and additional resources (see the *San Antonio River Basin Clean Rivers Program 2012 Basin Highlight Report and Watershed Characterization for Selected Watersheds* at <https://www.sara-tx.org/wp-content/uploads/2015/04/2012-Basin-Highlights-and-Characterization-Report.pdf> [San Antonio River Authority and Texas Clean Rivers Program 2012]). For impaired waters that fail to meet the Texas Surface Water Quality Standards defined in 30 TAC Chapter 307, Texas Commission on Environmental Quality requires development of total maximum daily loads (TMDLs) that identify the pollutant load reductions needed to meet water quality standards. Implementation plans (I Plan) for TMDLs are then developed, which often target pollutants by requiring the incorporation of BMPs; implementing LID offers an effective tool to improve water quality in these water bodies (USEPA 2009). For that reason, site planners should identify any impaired water or waters near or downstream of the site and determine the pollutants of concern to allow planners and designers to consider target pollutant reduction needs in the design phase. The Upper San Antonio I Plan (Lusk and Diehl, 2016) and Lower San Antonio River (Bryant and Koch, 2017) Watershed I Plans identified LID and stormwater BMPs as a management measure to address *E. coli* impairments in both watersheds.

Step 2: Define Natural Site Features

Site planners and designers should consider how to use existing natural features of the site in an effort to retain natural hydrologic functions and potentially reduce the cost of drainage infrastructure (see Appendix G for LID cost considerations). Identifying natural or sensitive areas is an integral factor in defining the site area for development and placing site needs and features in the context of the overall watershed.

To Complete Step 2:

- Identify natural areas to be conserved or restored
- Conduct a geotechnical survey including drainage characteristics, hydrologic flow paths, and soil infiltration tests

Naturally functioning areas

To enhance a site's ability to support source control and reduce runoff, natural areas that can infiltrate stormwater should be identified in the site design process and conserved or restored. These areas can intercept stormwater without engineered controls, thereby reducing the amount of runoff and the size and extent of drainage infrastructure. Such natural features can result in cost savings due to decreased infrastructure costs.

The following are fundamental principles encouraging conservation and restoration of natural areas:

Minimize site grading and the area of disturbance by isolating areas where construction will occur (See Step 5). Doing so will reduce soil compaction from construction activities. Additionally, reduced disturbance can be accomplished by increasing building density or height.

When possible, the site should be planned to conform to natural landforms and to replicate the site's natural drainage pattern. Building roads and sidewalks on the existing contour ensures that natural flow paths and hydrology continue to function.

An essential factor in optimizing a site layout includes conserving natural soils and vegetation, particularly in sensitive areas such as habitats of sensitive species, wetlands, existing trees, hillsides, conservation areas, karst features, and existing water bodies. Such areas can be used as natural features in site planning to avoid or reduce potential effects of development. Wetlands, for example, provide habitat for several sensitive species, and off-site mitigation does not always provide the same type or quality of habitat.

In areas of disturbance, topsoil can be removed before construction and replaced after the project is completed. When handled carefully, such an approach limits the disturbance to native soils and reduces the need for additional (purchased) topsoil later.

Impervious areas (e.g., square footage of parking lots, sidewalks, and roofs) should be minimized by designing compact, taller structures; narrower streets; and using underground or under-building parking.

In the example shown in Figure 1-10, the natural and sensitive areas that should be considered for protection during development are identified on the site map, including wetlands, high-quality vegetation, and steep slopes (hillside).

Understand soils through geotechnical surveys

Any project that includes LID practices should include a soil evaluation or geotechnical investigation. A licensed engineer (P.E.) with geotechnical expertise, a licensed geologist, engineering geologist, hydrogeologist, or other licensed professional acceptable to the local jurisdiction should perform a detailed evaluation of soils, shallow ground water and bedrock conditions. A soil evaluation including soil infiltration testing is intended to identify and protect soils that provide greater infiltration as potential locations for LID BMPs (Figure 1-10). The presence and depth to the seasonal water table or shallow bedrock should also be identified, which will inform BMP design under Phase II. In addition, natural drainage characteristics and hydrologic flow paths should be identified. These features can be used in the design and protected in future steps to maintain the site's natural drainage characteristics.

To Complete Step 3

- Protect areas of natural hydrologic function
- Protect possible areas for infiltration

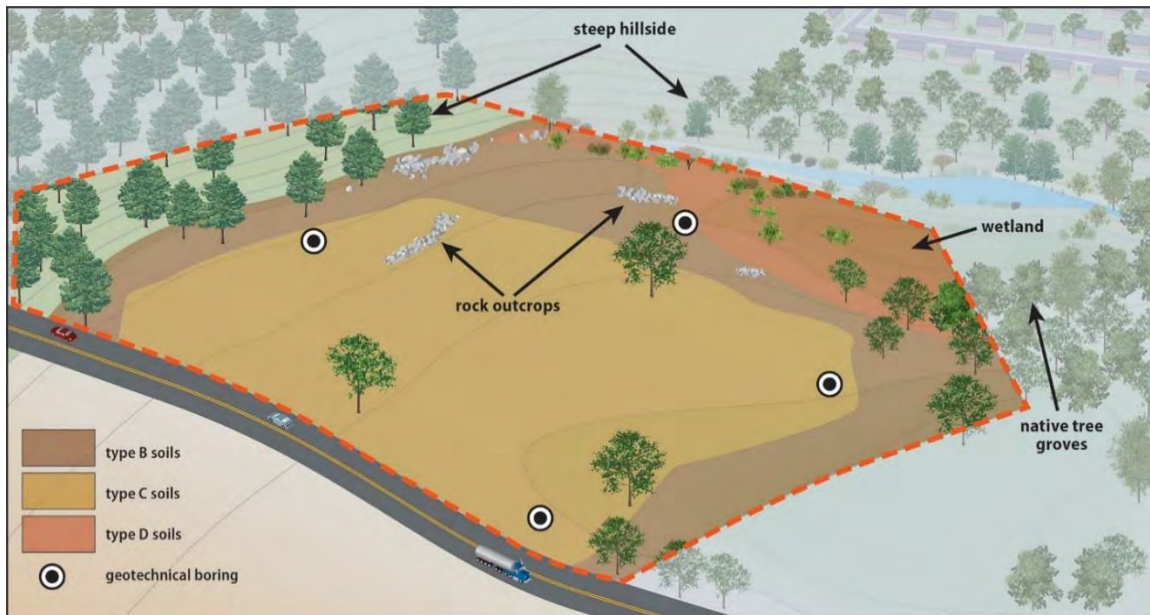


Figure 1-10. Protect natural and sensitive areas (wetlands, native tree groves, steep hillside) and conduct geotechnical survey to characterize infiltration capacity of soils

Step 3: Protect Key Hydrologic Areas

Following the LID site planning concept of using hydrology as the integrating framework, the key hydrologic areas such as hydrologic flow paths and infiltrating soils are protected. To the extent possible, natural hydrologic functions of the site should be preserved. Applying LID techniques results in a hydrologically functional landscape that can function to slow runoff rates, protect receiving waters, and reduce the total volume of runoff.

Second only to flow regimes in ensuring proper hydrology, healthy soils or media often serve as essential elements for achieving LID functions and providing source control for stormwater treatment. For example, upper soil layers are conducive to slowly filtering and storing stormwater, allowing unit processes such as infiltration, sorption, evapotranspiration, and surface retention to occur.

Site features that should be protected are riparian areas, floodplains, stream buffers, wetlands, karst or sensitive geological features, recharge features, heritage or native tree groves, and soils with infiltration potential. Using the information collected in the Step 2 soil evaluation, more specific locations of soils with greater infiltration rates that are near or on hydrologic flow paths should be protected to avoid or limit hydrologic impacts. As an example, Figure 1-11 indicates the key hydrologic areas that should be considered for protection. The blue area identified as an area for possible infiltration should be separated from other site features by surrounding it with construction fencing to prevent access and avoid compaction. In addition, the areas having a natural hydrologic function either through storage or conveyance should be protected (also see Figure 1-11 in setting site clearing and grading limits).

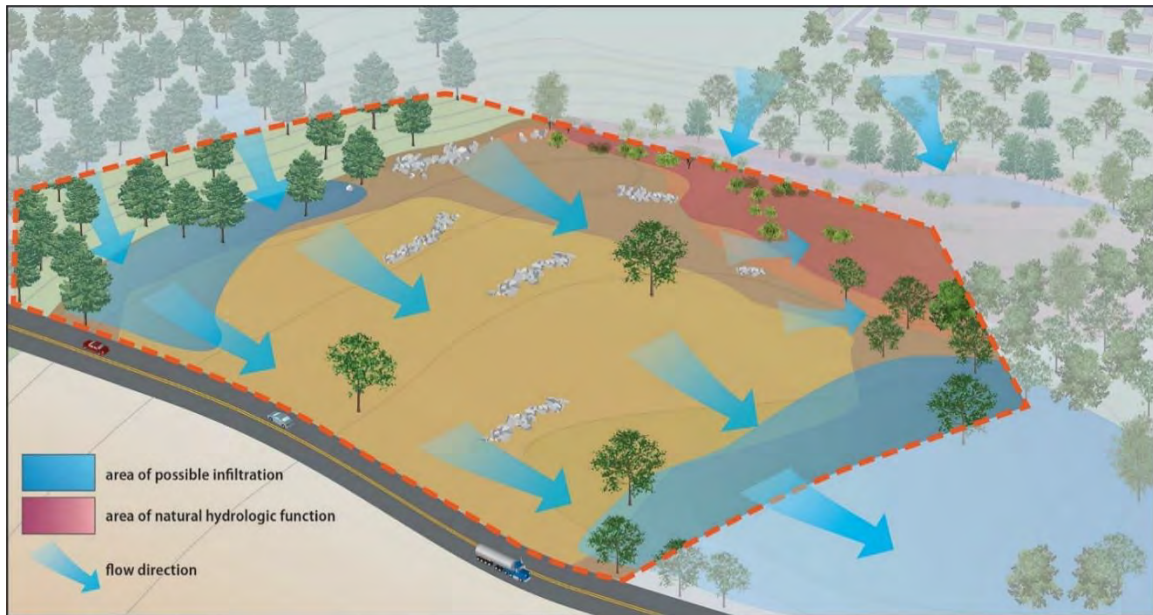


Figure 1-11. Identify and protect key hydrologic areas, such as infiltrating soils (blue area) and wetlands (orange areas)

With the conclusion of Phase I, the initial site assessment has been completed. The decisions made regarding LID practices during the site assessment process should be documented to ensure that if changes are required in future Phases II and III, the original design ideas are available for reference. That helps ensure that LID concepts are considered during every component of project site planning. Phase II of site planning, described below, results in a preliminary design plan.

1.6.2 Phase II—Preliminary Design

The result of the second phase of site planning is a completed preliminary design done by conducting Steps 4 through 7, below. Working through those steps is an iterative process for designing a preliminary plan that implements LID concepts as fully as possible.

Step 4: Use Drainage and Hydrology as a Design Element

Natural hydrologic functions (e.g., flow paths) should be included as a fundamental component of the preliminary design. Naturally present functions should be retained, or if that is not an option, replicate natural functions with appropriate BMP placement.

To Complete Step 4:

- Identify the spatial layout of the site using hydrologic flow paths and natural drainage as a feature
- Determine approximate locations for infiltration and conveyance BMPs

Spatial site layout options

Natural hydrologic functions, including interception, depression storage, and infiltration, should be distributed throughout the site to the extent possible. In conserving predevelopment and retrofit hydrology, one must consider runoff volume, peak runoff rate, flow frequency and duration, and water quality control. Rainfall abstractions are the physical processes of interception, evaporation, transpiration, infiltration, and storage of precipitation.

Runoff flow frequency and duration should try to mimic predevelopment conditions by implementing practices to minimize runoff volume and rate. LID practices also provide pollutant removal processes that enhance water quality treatment for the designed treatment volume.

By setting the development envelope back from natural drainage features, the drainage can retain its hydrologic functions and its water quality benefit to the watershed as shown in the example in Figure 1-12, assuming that runoff from the contributing watershed is mitigated to predevelopment conditions.

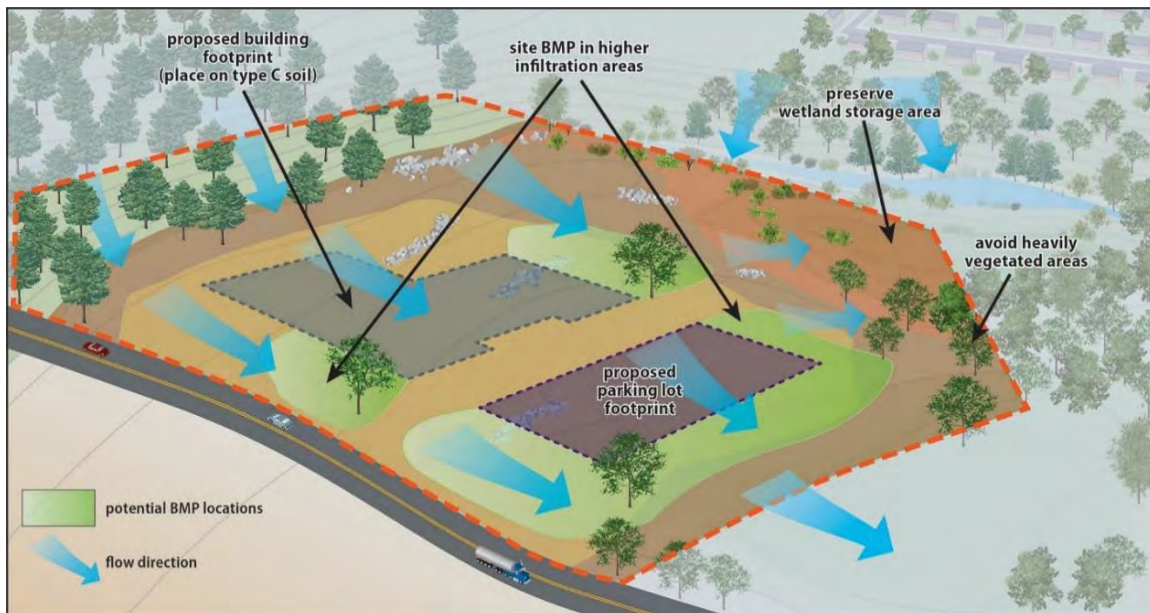


Figure 1-12. Identify ideal locations for LID implementation according to site conditions

Spatial layout should use the natural landforms and hydrologic flow paths identified in Step 2 as a major design element of the site. Common elements using that premise include designing open drainage systems to function as both treatment and conveyance devices. Impervious elements such

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as parking lots, roadways, and sidewalks can be designed on the existing contour to minimize effects on the natural hydrologic flow path.

Determine potential BMP locations

Stormwater management practices can be designed to achieve water quality and flood protection goals by applying four basic elements, alone or in combination: infiltration, retention/detention, filtration, and evapotranspiration.

Infiltration systems should be designed to match predevelopment hydrology and to infiltrate the majority of runoff from small storm events, when applicable and to the extent possible. Existing site soil conditions generally determine whether infiltration is feasible without soil amendments or underdrains. Other site conditions that preclude infiltration are high ground water, steep slopes, or shallow bedrock. Infiltration systems can also help control peak flow rates by providing retention and volume control.

Retention/detention systems are intended to store runoff for gradual release or reuse. Retention/detention basins also allow for evaporation of runoff and evapotranspiration by plants. They are most appropriate where soil percolation rates are low or where longer retention times are designed into the system. They are also appropriate when designing to control peak flow rates for downstream flood and channel protection.

Stormwater management practices can be designed to achieve water quality and flood protection goals by applying four basic elements: infiltration, retention/detention, filtration, and evapotranspiration.

Biofiltration devices are designed using vegetation to achieve low-velocity flows, to allow settling of particulates and filtering of pollutants by vegetation, rock, or media. Pollutant degradation can also occur through biological activity and sunlight exposure. Biofilters can be designed to be linear features that are especially useful in treating runoff from parking lots and along highways.

Evapotranspiration is inherent in all BMP systems. Evaporation is maximized in systems that retain or detain runoff, and vegetated systems maximize transpiration as plants use the stored water for growth.

Selecting the appropriate structural BMPs for a project area should be on the basis of site-specific conditions (e.g., land availability, slope, soil characteristics, climate condition, and utilities) and stormwater control targets (e.g., peak discharge, runoff volume, or water quality targets).

In the example shown in Figure 1-12, areas are identified that will be developed for parking and building footprints. The figure also indicates ideal locations where LID BMPs can be placed (such as a biofiltration swale and bioretention) and can be incorporated into the natural drainage paths to function as conveyance and treatment LID BMPs. The infiltration opportunities identified in Figure 1-11 suggest that the green highlighted area near the road (Figure 1-12), which is on hydrologic soil group C, would be more suitable for a biofiltration BMP, while much of the rest of the potential BMP area is on hydrologic soil group B, indicating that this area would be better for infiltration systems. Note that both biofiltration and infiltration BMPs can also meet landscaping requirements and create features that enhance and beautify the site. Consider opportunities for placement of more than one BMP in series, instead of one that treats runoff for the entire site.

Step 5: Establish Clearing and Grading Limits

Limits of clearing and grading refer to the total site area that is to be developed, including all impervious and pervious areas. The area of development ideally should be in less sensitive locations with respect to hydrologic function and should be outside protected areas and areas containing setback regulations, easements, and utilities.

To Complete Step 5:

- Define the limits of clearing and grading
- Minimize disturbance to areas outside the limits of clearing and grading

Site fingerprinting refers to site clearing and development with minimal disturbance of existing vegetation and soils. Such techniques include reducing paving and compaction of highly permeable soils, minimizing the size of construction easements and material storage areas, site clearing and grading to avoid tree removal, delineating and flagging the smallest site disturbance area possible, and maintaining existing topography to the extent possible. Figure 1-13 illustrates the use of orange construction fencing to preserve the natural features, drainage pathways, and maintain infiltration on suitable soils at the example site as identified in previous steps.

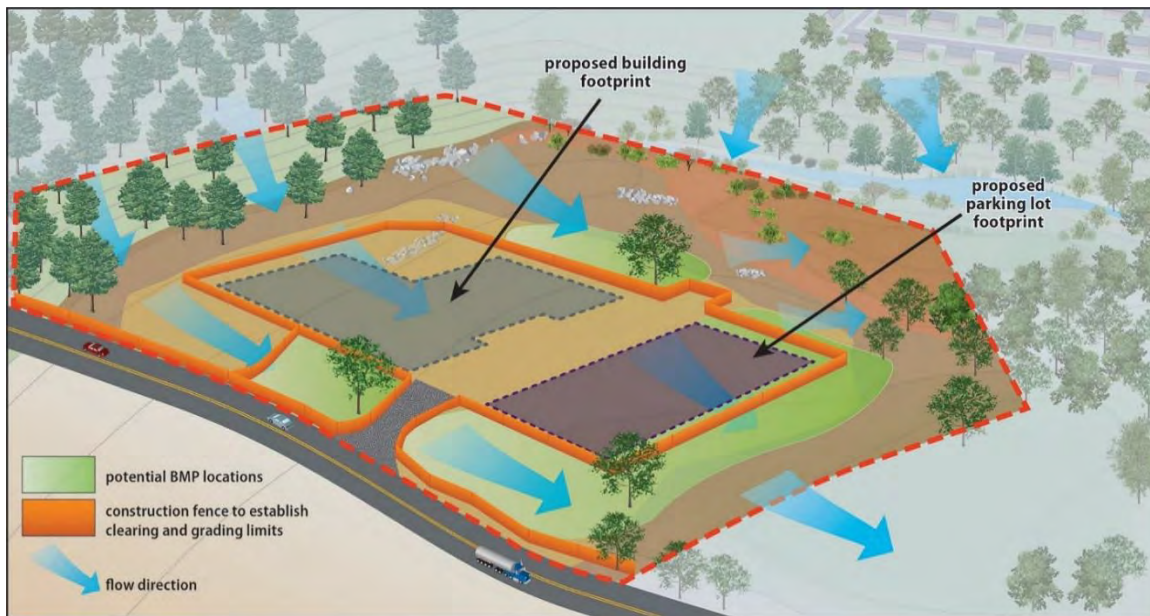


Figure 1-13. Establish grading envelope to protect natural areas and infiltrating soils

Step 6: Reduce/Minimize Total and Effective Impervious Area

Rainfall that does not infiltrate or pool where it falls results in runoff. As the imperviousness of the site increases, runoff also increases with each acre of impervious cover producing approximately 27,150 gallons of stormwater for each inch of rainfall. Predevelopment runoff, measured as a runoff coefficient or the ratio of runoff volume to the total amount of rainfall,

To Complete Step 6:

- Investigate the potential for impervious area disconnection
- Evaluate the conceptual design to reduce impervious surfaces

can be maintained by compensating for increases in impervious areas, soil compaction, and the loss of abstraction through planning and design. Such tools can be used to also manage the peak runoff rate and volume and protect water quality.

Disconnect impervious area

Diverting stormwater runoff from impervious areas such as rooftops and pavement to adjacent pervious areas can be used to infiltrate stormwater runoff and to reduce flow rates (shown in Figure 1-13). Proper design can align pervious surfaces with building drainage. Such a technique is also referred to as impervious area disconnect.

To reduce the storage and conveyance requirements, the directly connected impervious area of the site should be minimized to the extent practicable. That can be accomplished by increasing the building density by increasing the vertical extent and minimizing the horizontal extent. Impervious area disconnect can also include using permeable features instead of impermeable including permeable pavement for walkways, trails, patios, parking lots, and alleys; and constructing streets, sidewalks, and parking lot aisles to the minimum width necessary. Impervious area disconnection can provide good opportunities for treatment train systems, where vegetative filter strips or permeable pavement can function as the first BMP in the treatment train.

Possible locations for impervious area disconnect techniques are shown in Figure 1-14 below in yellow. As shown in the figure, the medians along either side and in the middle of the roadway provide vegetated pervious areas for minimizing or reducing the impacts associated with the total impervious area and for infiltration and filtration processes to take place. The figure also demonstrates the use of pervious pavement in the parking lot and along the roadway (in red).



Figure 1-14. Site example demonstrating placement of pervious material (red) and opportunities to minimize connected impervious area (yellow)

Minimize impervious area

Street layouts often can be designed to reduce the extent of paved areas, and street widths can be narrowed to decrease the total impervious area as long as applicable street design criteria are satisfied. Eliminating curbs and gutters along streets and including curb cuts around parking areas, where consistent with city standards and where appropriate, can promote drainage to on-site pervious areas and decrease directly connected area considerably. Other options include replacing curbs and gutters with roadside vegetated swales and directing runoff from the paved street or parking areas to adjacent LID facilities. Such an approach for alternative design can reduce the overall capital cost of the site development while addressing stormwater quantity and quality issues and improving the site's aesthetic values. Figure 1-14 illustrates the inclusion of pervious paving and bioretention systems with curb cuts along the street right-of-way to demonstrate locations where that can be achieved.

Specific examples of alternative transportation options include narrow paved travel lanes, consolidated travel lanes, increased green parking areas, and horizontal deflectors (chicanes) or intersection pop-outs. Such options can be included for other multi-beneficial purposes such as traffic calming and pedestrian safety (Ewing 1999), increased parking spaces, and improved aesthetics. Four examples of transportation alternatives are described below.

Narrowed travel lanes: Narrow travel lanes can help reduce impervious area and infrastructure costs, calm traffic in pedestrian-oriented areas, and create room for stormwater facilities. Existing roadways can be narrowed to minimum widths in accordance with established roadway standards. Residential street crossings are often combined with traffic-calming measures, which reduce street width and are designed to maintain low vehicle speeds, such as raised crosswalks, chicanes, and gateway narrowing.

Consolidated travel lanes: Consolidating travel lanes or converting unused pavement next to travel lanes into landscape areas can result in reduced imperviousness. The increased landscape space could be used for stormwater facilities and create space for bike lanes, wider sidewalks, and a more balanced and vibrant streetscape. Parking lanes can also be converted to permeable paving that can be used for stormwater management.

Increased green parking: Techniques used to reduce the total impervious coverage and consequential runoff from parking lots are broadly referred to as *green parking*. Green parking techniques include minimizing the number and dimension of parking stalls, using alternative pervious pavers wherever suitable, incorporating stormwater BMPs such as depressed bioretention islands into parking lot designs, encouraging shared parking and incentivizing structured parking (Figure 1-14). When implemented together, green parking alternatives reduce volume and the mass of pollutants generated from parking lots, reduce the urban heat island effect, and enhance a site's aesthetics.

Intersection deflectors (chicane): A chicane is a traffic channelization that causes a series of tight turns in opposite directions in an otherwise straight stretch of road (City of San Antonio 2013). The combination of narrowed street width and the serpentine path of travel slow traffic (Figure 1-15). On new streets, chicanes narrow the street by widening the sidewalk or landscaped parkway. On streets considered for retrofit, raised islands can be installed to narrow the street. Advantages of chicanes include reduced traffic speeds, opportunities for landscaping, and created spaces for stormwater management facilities. Chicanes are inappropriate for use on streets classified as

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collector or higher, bus routes, emergency response routes, where there is a grade that exceeds 5 percent, or where stopping sight distance is limited such as at the crest of a hill.



Figure 1-15. Bioretention incorporated into a pop-out, Kansas City, Missouri. Source: Tetra Tech

Intersection pop-outs: Intersection pop-outs are curb extensions that narrow the street at intersections by widening the sidewalks at the point of crossing. They are used to make pedestrian crossings shorter and reduce the visual width of long, straight streets (Figure 1-16). Where intersection pop-outs are constructed by widening the landscaped planting strip, they can improve the aesthetics of the neighborhood and provide more opportunities for stormwater controls at the site by facilitating interception, storage, and infiltration. Intersection pop-outs should be designed to properly accommodate bicyclists, transit vehicles, and emergency response vehicles. Intersection pop-outs can be installed on local streets; however, pop-outs are inappropriate on major streets and primary arterials.



Figure 1-16. Intersection pop-out, River House, San Antonio, Texas.

Many LID street design features can have multiple benefits in addition to stormwater benefits. The San Antonio Complete Streets Initiative, developed in 2011, includes a provision that states, “San Antonio will encourage green infrastructure and LID principles on Complete Streets to help manage stormwater runoff and provide landscaping amenities” (City of San Antonio 2011). Complete Streets offer opportunities to incorporate stormwater BMPs while enhancing safety and convenience for pedestrians, bicyclists, individuals with disabilities, seniors, and users of public transportation.

Reduced width of road sections can also reduce total site imperviousness. Streets, sidewalks, and parking lot aisles should be constructed to the minimum width possible without compromising public safety and access. Additionally, sidewalks and parking lanes can be limited to one side of the road.

Traffic or road layout can significantly influence the total imperviousness of a site plan. Selecting an alternative road layout can result in a sizeable reduction in total site imperviousness. Alternative road layout options that can reduce imperviousness from the traditional layout pattern use queuing lanes, parking on only one side of the street, incorporating islands in cul-de-sacs, and using alternative turn areas that require less pavement (CWP 1998).

Other transportation opportunities for reducing impervious area include using shared driveways, limiting driveway widths to 9 feet and using driveway and parking area materials that reduce runoff and increase the time of concentration (e.g., grid systems and paver stones).

Several iterations of manipulating site imperviousness can be done to consider natural features, areas of infiltration, and hydrologic pathways to best achieve a balance between necessary imperviousness with disconnected and pervious site features. Once the total area of imperviousness has been minimized, the impervious areas can be incorporated into the site plan or capital improvement roadway project.

In Figure 1-14 opportunities for imperviousness reduction and runoff disconnection were identified for both the building site and for alternative transportation options. The sidewalk surrounding the building was disconnected by routing runoff to the pervious landscaped areas surrounding the building (shown in yellow) and pervious paving was identified in the low-traffic areas of the parking lot to reduce site imperviousness. Pervious paving was also identified as an opportunity for reduction in impervious area for on-street parking (shown in red) and a median bioswale along with right-of-way bioretention were identified as methods for runoff disconnection (shown in yellow).

Step 7: Determine LID BMPs

LID BMPs employ a number of processes: settling/sedimentation, filtration, sorption, photolysis, biological processes (bioaccumulation and biotransformation/phytoremediation), and chemical processes (for complete descriptions, see [Section 3.3](#)) for pollutant removal. In addition to pollutant removal, LID BMPs provide hydrologic controls by reducing peak flows and volume through processes of infiltration, evaporation, and storage and reproducing predevelopment hydrologic functions.

To Complete Step 7:

- Determine potential BMPs according to hydrologic and pollutant removal process needs and cost estimates (see [Chapter 3](#))
- Repeat Steps 4 through 7 as necessary to ensure that all stormwater management requirements are met

During BMP selection, it is important to consider a BMP's unit processes to ensure that the management practice will provide the necessary benefits and avoid potential complications.

Hydrologic controls dictate how incoming stormwater is partitioned into the various components of the hydrologic budget. Stormwater volume can be detained, infiltrated, evapotranspired, drained, or bypassed depending on the design of hydrologic controls and features such as impermeable liners, underdrains, inlet and outlet structures, soil media permeability, and storage capacity.

Settling/sedimentation is the physical process of particle separation as a result of a difference in density between the solids and water. Most BMPs use settling to some degree, especially through detention or retention practices such as bioretention. Settling is enhanced by slowing down or spreading out runoff to create low velocity flow conditions.

Filtration is the physical process of separating solids from a liquid media; particles are filtered from water by the smaller interstitial space the water flows through in the porous medium. Sedimentation and sorption can also occur as water passes through a filtering practice. *Sorption* refers to the processes of *absorption* (an incorporation of a pollutant into a substance of a different state) and *adsorption* (the adherence of a pollutant to the surface of another molecule). Sorption is also referred to under chemical treatment processes. Filtration is a common unit process in a number of BMPs such as bioretention and planter boxes.

Floatation is a treatment unit process where the mechanism for pollutant removal is opposite to that in settling and sedimentation. In floatation, the density of pollutants, such as trash and petroleum, is less than that of water. Oil/water separators and trash guards are the primary BMP practices that use floatation.

Biological treatment processes (bioaccumulation, biotransformation, phytoremediation) are processes that occur in practices that incorporate soils and plants for pollutant removal via biological transformation or mineralization, pollutant uptake and storage, or microbial transformation. It can also include organisms that consume bacteria. BMPs that can be designed to use such unit processes are bioretention, bioswales, and planter boxes.

Chemical treatment processes include sorption, coagulation/flocculation, and disinfection. Chemical characteristics of stormwater such as pH, alkalinity, and reduction-oxidation (redox) potential, determine which chemical process is appropriate. Sorptive BMPs generally include engineered media for removing pollutants of concern. Precipitation and disinfection processes require actively adding chemicals to encourage coagulation/flocculation and precipitation or chemicals such as chlorine to mitigate pathogenic microbes in stormwater. Chemical treatment processes are usually employed as end of pipe solutions where no other BMP can effectively treat an existing storm drain system. In these cases, low flow may be more effectively treated by pumping into a sanitary sewer.

Using multiple treatment processes either in individual or multiple BMPs is called a *treatment train*. Meeting targeted treatment objectives can usually be achieved using a series of LID BMPs in a treatment train. Treatment trains can often be designed along rights-of-way, in parking lots, underground, or incorporated into landscaped areas. LID site planning should result in a treatment train of LID strategies and BMPs to meet treatment and water quality goals. For further details on treatment train BMP implementation, see [Section 3.3](#).

Treatment trains can be designed to combine BMPs which utilize different unit processes to create design flexibility for sites while maximizing treatment. Using the same type of BMP multiple times in series tends to provide lower overall removal efficiency compared to using diverse BMPs in series (TCEQ, 2015). In general, the highest level of pollutant removal is typically achieved in the first BMP and as the pollutant concentration decreases, each of the successive BMPs would be less effective than that BMP on its own (MN, 2018). The subsequent BMPs in the treatment train, as a result, will generally have a decreased removal efficiency (expressed as percent reduction), although the final effluent concentration will be lower with BMPs in series than what each BMP could achieve individually. The disadvantages of treatment train systems are the additional costs associated with the increased pollutant reductions, reduction in the economy of scale benefit for increasing the size of BMPs, and the additional operational and maintenance cost that could be incurred.

A number of factors should be considered for choosing appropriate BMPs for a site. For example, the presence of group C or D soils on a site might preclude the use of an infiltration BMP or require the use of an underdrain into the design of infiltration BMPs (see Appendix B, Section 11.4). Additionally, the low level of precipitation and high evapotranspiration rates usually present in San Antonio would likely exclude the use of a BMP requiring a permanent pool, such as a stormwater wetland, because precipitation is not great enough to maintain a continual or permanent pool of water. Native vegetation, which is adapted to the local climate and soils, should be used for

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vegetated BMPs, as much as possible, when soils allow. If native soils are replaced with imported soils to improve infiltration, non-native non-invasive but drought-tolerant plants might be a desired choice. For a table of appropriate vegetation, see Appendix E. Other geotechnical, site-specific considerations include the level of the underlying water table and bedrock, any existing infrastructure in retrofit designs, and the presence of areas of concern that exhibit soil and ground water contamination.

The information gathered and organized during Steps 1–6 provide the foundation for selecting BMP types that are most appropriate to meet the stormwater management needs of the site. Chapter 3 of this manual summarizes information about specific LID BMPs and provides thorough guidance on selecting appropriate LID BMPs for a site. Table 3-1 in [Chapter 3](#) succinctly summarizes the selection criteria and should be consulted to assist in the process. Additionally, Appendix B provides substantial detail about BMP applicability and design requirements and can be referenced during the process.

At the completion of Phase II, the site planning for the project is complete. At that point in the site planning process, the development area should be delineated and the approximate type and potential locations for appropriate BMPs should be identified. The preliminary plan should be documented in addition to the decisions that were made in developing the preliminary plan for future reference and to ensure that the LID planning concepts are carried through to project construction. After the preliminary design is completed, the final design is achieved through identifying the appropriate LID facility type and size for meeting stormwater management needs and requirements.

Using multiple treatment processes either in individual or multiple BMPs is called a treatment train.

The example shown in Figure 1-17 indicates the approximate type and locations of potential stormwater management practices. The type, size, or location could change according to site construction or other site design changes and requirements.

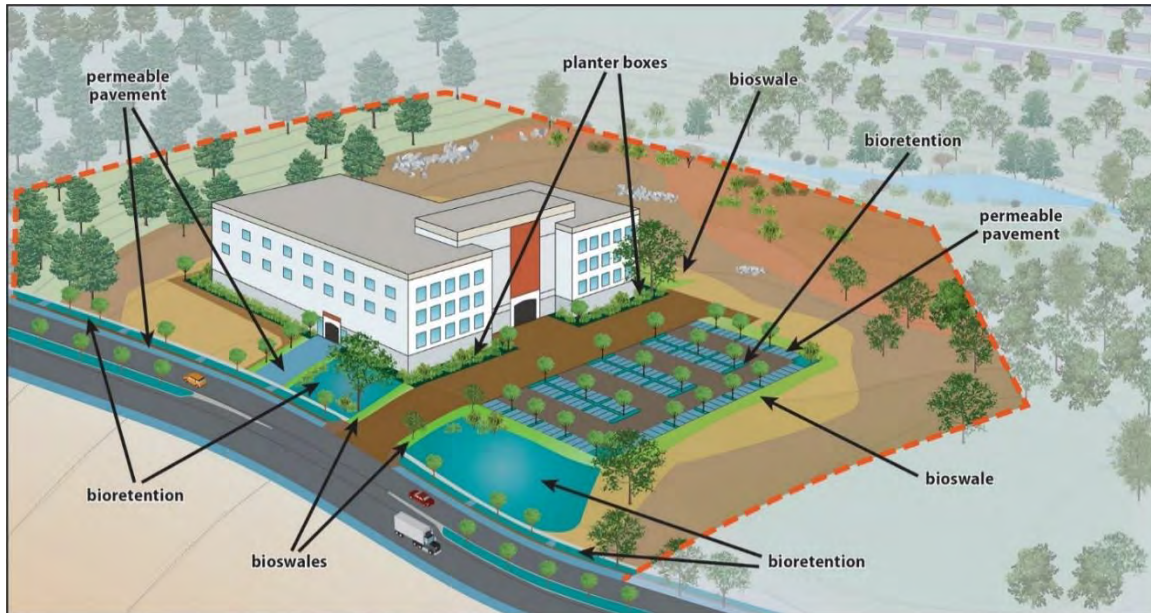


Figure 1-17. Site plan indicating all possible BMP locations (blue areas) and types (annotated)

Results of Phase II

The analyses in Phase II should produce a preliminary site plan that includes

- Hydrologic flow paths and natural drainage features (Step 4)
- Locations where infiltration and conveyance features could be located (Step 4)
- Limits of clearing and grading (Step 5)
- Results of an impervious area reduction analysis (e.g., parking area reduction, permeable pavement options) (Step 6)
- Candidate BMPs (see [Chapter 3](#)) and their approximate locations (Step 7).

1.6.3 Phase III—Determine Low Impact Development Final Design

Step 8: Determine Approximate Size of LID BMPs

The level of control that is required for a site to achieve stormwater management goals can be determined through a site-specific hydrologic evaluation. The hydrologic evaluation is performed using hydrologic modeling and analysis techniques. A stepwise process is followed to conduct a hydrologic evaluation:

To Complete Step 8:

- Determine the approximate BMP size using the BMP sizing tool (Appendix A)

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1. Delineate the watershed and subwatershed areas.
2. Define the design storm (for BMP sizing guidance, refer to Appendix A and the “Size the System” subsections of Appendix B).
3. Determine the type of model to be used.
4. Collect data for predevelopment conditions.
5. Using hydrologic models, evaluate predevelopment, baseline conditions.
6. Using hydrologic models, evaluate the hydrologic benefits from decreasing and disconnecting impervious areas, and compare the benefits to baseline conditions.
7. Using hydrologic models, evaluate the hydrologic control from implementation of one or more LID BMPs.

Step 9: LID Final Design

Following iterations of Steps 4–7 and BMP sizing in Step 8, additional conventional stormwater control techniques can be added to the site as necessary to meet site drainage and other requirements (Figure 1-18). Review of the earlier documentation of decisions made during planning phases should also be conducted to ensure that the intent of the LID planning principles were carried through to the final design. The iterative review process can result in more or less area required for stormwater management. Notice that in Figure 1-18, the iterative process resulted in the elimination of planter boxes at the base of the building as the other LID BMPs provided the required volume of capture.

The key to finalizing the BMP design process is to consult the design instructions for the selected BMP types in Appendix B of this manual. By following those instructions and using the example engineering drawing templates in Appendix C, the designer can develop final details, plan views, cross sections, profiles, and notes. The example shown in Figure 1-18 illustrates the final site layout, including the properly sited and sized BMP locations.

To Complete Step 9:

- Integrate conventional stormwater management needs
- Verify that geotechnical and drainage requirements have been met
- Complete BMP designs such as finish details and notes
- Complete the site plans



Figure 1-18. Completed site plan including iterations of Steps 4–7 and BMP sizing completed

Completing Step 9 concludes Phase III of the design process. Chapter 4 provides important considerations for the design, construction, and operation of the chosen BMPs, including BMP construction, inspection, and operation and maintenance.

1.7 Multiple Benefits of LID

Proper stormwater management achieves several important purposes for municipalities and developers. Restoring predevelopment hydrology and realizing associated water quality benefits are of primary importance, particularly with respect to stormwater pollution effects on aquatic life habitats. Degraded water quality will also negatively affect or restrict recreational opportunities by limiting contact with surface waters and reducing recreational fishing opportunities. Loss of these recreational resources in the San Antonio region can negatively impact local economics and the quality of life for San Antonio residents. Another factor to consider is that local drinking water supplies rely heavily on ground water recharge and can be impacted by poor surface water quality.

Considerable cost savings over traditional approaches often can be achieved through proper stormwater management and LID implementation.

In addition to reducing flood hazards (Medina et al. 2011) and protecting and enhancing water quality (USEPA 2009), stormwater management systems or programs should be designed to comply with federal and state regulatory requirements. Relevant regulations are discussed in [Chapter 2](#) and Appendix G. Ancillary to the direct water pollution benefits of LID, these practices can reduce the cost of TMDL implementation incrementally. Where stormwater fees are levied, green infrastructure can reduce the cost to implement the stormwater management program because the amount of stormwater needing treatment on a regional scale is reduced.

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Considerable cost savings over traditional approaches often can be achieved through proper stormwater management and LID implementation. For example, LID practices typically involve less construction material, replacing structures such as pipes with natural materials (plants, soils), and have been found to reduce the overall cost of stormwater management (USEPA 2012b). Additionally, maintaining LID BMPs at the surface is typically less expensive than subsurface storage units or conveyance pipes. **Finally, controlling stormwater runoff and associated pollutants on-site decreases the costs of mitigation and restoration activities.**

From a life cycle perspective, the long-term costs of maintenance and replacement can be lower for LID practices because their vegetation becomes enhanced as it grows over time, whereas traditional engineered materials tend to deteriorate over time. Also, LID maintenance typically does not require heavy equipment or specialized expertise, whereas maintaining pipes, forebays, basins, and embankments can be more costly.

The visible, above-ground and accessible qualities of LID practices provide additional benefits when compared to traditional drainage infrastructure, including educating the public, creating habitat for wildlife, improving air quality, improving aesthetics, and offering recreational opportunities (CNT 2010). Because of its visible nature, LID offers enhanced public education opportunities, especially when signage is used to inform viewers of the features and functions of the various types of facilities.

Vegetated LID practices can provide air quality benefits, particularly those that incorporate trees. Trees absorb air pollutants, notably carbon dioxide (CO₂) but also nitrogen dioxide (NO₂), ground-level ozone (O₃), sulfur dioxide (SO₂), and particulate matter that is 10 µm or smaller (PM-10). Green infrastructure's ability to sequester carbon in vegetation can help to meet greenhouse gas emission goals by contributing to a carbon sink (CNT 2010).

Trees create shade that reduce indoor air temperatures and reduce the demand for energy for cooling. This yields direct cost savings to electricity consumers and, through reduced electricity demand, reduces air pollution emissions from electricity generation. Reduced emissions of air pollution benefits human health through lowered incidence and severity of respiratory ailments and reduces costs associated with air quality regulation compliance (ECONorthwest 2011).

Green infrastructure that includes trees and other vegetation can reduce the urban heat island effect, which is the phenomenon of urban area temperatures that are several degrees higher than surrounding rural land uses. The U.S. EPA (2012b) indicates that annual mean air temperature can be 1.8 °F to 5.4 °F higher in urban centers and up to 22 °F higher in the evening. Tree cover does not absorb heat like pavements do, and trees reduce temperatures through shading and evapotranspiration. Reducing urban heat islands through tree planting achieves energy reduction (reduced need for cooling, along with the ancillary benefits described above) and can reduce the incidence and severity of heat-related illnesses.

The visible, above-ground and accessible qualities of LID practices provide additional benefits when compared to traditional drainage infrastructure.

Green infrastructure that includes attractive vegetation can improve property aesthetics, which can translate into increased property values (Table 1-1). This vegetation also provides habitat for urban wildlife, particularly birds and insects, even at small scales of implementation. Larger-scale

facilities that include public access, such as constructed wetlands, offer recreational opportunities (e.g., fishing, bird-watching) as well as habitat for wildlife and water quality/quantity improvements.

Table 1-1. Studies showing increased property values related to LID and open space

Source	Percent increase in property value	Notes
Ward et al. (2008)	3.5 to 5%	Estimated effect of green infrastructure on adjacent properties relative to those farther away in King County (Seattle), WA.
Shultz and Schmitz (2008)	0.7 to 2.7%	Referred to effect of clustered open spaces, greenways and similar practices in Omaha, NE.
Wachter and Wong (2008)	2%	Estimated the effect of tree plantings on property values for select neighborhoods in Philadelphia.
Anderson and Cordell (1988)	3.5 to 4.5%	Estimated value of trees on residential property (differences between houses with five or more front yard trees and those that have fewer), Athens-Clarke County (GA).
Voicu and Been (2008)	9.4%	Refers to property within 1,000 feet of a park or garden and within 5 years of park opening; effect increases over time
Espey and Owusu-Edusei (2001)	11%	Refers to small, attractive parks with playgrounds within 600 feet of houses
Pincetl et al. (2003)	1.5%	Refers to the effect of an 11% increase in the amount of greenery (equivalent to a one-third acre garden or park) within a radius of 200 to 500 feet from the house
Hobden, Laughton and Morgan (2004)	6.9%	Refers to greenway adjacent to property
New Yorkers for Parks and Ernst & Young (2003)	8 to 30%	Refers to homes within a general proximity to parks

Some evidence exists that residents' health and well-being are improved by the presence of larger-scale green space that offers recreational opportunities (Stratus Consulting 2009). Riparian area improvements that enhance stream stability can include recreational trails for walking, running, and biking. Also, creation of parks, green space, and plaza space into which green infrastructure can be integrated can create gathering spaces for local residents.

Green infrastructure can be used in concert with public safety measures to enhance walkability. Green streets that include curb pop-outs at pedestrian crossings improve pedestrian safety by slowing traffic and decreasing the distance that pedestrians must travel in the roadway.

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2. Regional Considerations

2.1 Physical Features and Climate

The San Antonio River basin is ecologically diverse, with portions of five of Texas' ten ecoregions: the Edwards Plateau (Hill Country), the Blackland Prairie, the Post Oak Savannah, the South Texas Plains, and the Gulf Coast Prairies and Marshes. Bexar County contains the largest portion of urban area of the four counties and is thus covered in more detail in this Manual. However, the guidelines provided in this Manual are applicable to all four counties. Bexar County elevations range from 600 feet above sea level in the southeast corner of the county to about 1,900 feet above sea level in the northwest extents. Elevations drop to 40 feet above sea level in Goliad County. Bexar County is bisected by the Balcones Escarpment, a geologic fault zone that divides the Edwards Plateau from the coastal plains. The escarpment also serves as a mild climatic influence by pooling moisture-laden air carried on the prevailing southeasterly winds from the Gulf of Mexico. Rainfall for the four counties averages 26 to 34 inches per year, according to mean annual precipitation data (1981–2010) from Oregon State University's PRISM Climate Group. According to TCEQ, more than three quarters of the annual rainfall volume is delivered by storms with less than 1-inch depth (TCEQ 2005). It is also common for little to no rainfall to occur for periods of 60–90 days, which creates significant plant stress. In this context, an understanding of soils, geology, topography, climate, native vegetation, and pre-development land cover and hydrology is necessary for optimizing application of LID.

2.1.1 Soils and Geology

One of the fundamental concepts of LID is to use the infiltration capacity of the native soils to the extent possible to mimic natural hydraulic conditions. This stormwater management concept is unique to LID design strategies where a smaller design storm (typically between 1 and 1.5 inches) is targeted. In contrast, current local development codes are geared toward conservative flow estimates that are used to size road and drainage infrastructure. The local regulatory focus on flood control is important because Bexar County is located in a region known as “Flash Flood Alley” (see <http://floodsafety.com/>). During the regulatory 1 percent annual chance design flood, infiltration capacity is much less significant given the runoff volume of the target storm. However, infiltration can have a significant impact in runoff volume reduction for the typical LID design storm, making actual soil type an integral design parameter.

One of the fundamental concepts of LID is to use the infiltration capacity of the native soils to the extent possible to mimic natural hydraulic conditions.

Bexar County soil types present a wide variety of opportunities and challenges for stormwater management. As described in previous sections, a site assessment to evaluate infiltration capacity will be required to determine the most appropriate location for BMPs and the most effective treatment train. This assessment must extend deep enough to determine whether shallow groundwater or rock layers will reduce infiltration capacity once surface soils are saturated. Site geotechnical analyses are further discussed in [Chapter 4](#).

Chapter 2: Regional Considerations

Bexar County soil characteristics vary widely from thin calcareous clays to deep sandy loams. Vegetation establishment in the Edwards Plateau region is particularly challenging because of soil loss. The region was developed through ranching because the land was difficult to plow. It is predominantly used for grazing cattle, sheep, goats, exotic game animals, and native wildlife (Griffith et al. 2004). Today, poor quality forbs and grasses dominate much of the Edwards Plateau with juniper woodland being the dominant plant habitat of the region (TPWD no date). Juniper is particularly detrimental to the establishment of a good soil profile because its needles are toxic to native grass species that contribute to soil formation and stabilization through growth and die-off of deep root systems. Soil loss under and between juniper canopy results in less interception and infiltration of rainfall. In areas impacted by agricultural operations (including ranching) it is important to understand that pre-development hydrology likely produced less runoff than modern land cover. Watershed protection or restoration through LID can increase infiltration and improve groundwater resource availability.

Soils are classified into four hydrologic soil groups (HSG) by the Natural Resources Conservation Service (NRCS) on the basis of the soil's potential for runoff. The NRCS soil groups are as follows:

- Soil Group A: sand, loamy sand, or sandy loam, which have low runoff potential and high infiltration rates even when thoroughly wetted.
- Soil Group B: silt loam or loam, which have a moderate infiltration rate when thoroughly wetted.
- Soil Group C: sandy clay loam, which has low infiltration rates when thoroughly wetted.
- Soil Group D: clay loam, silty clay loam, sandy clay, silty clay, or clay, which have very low infiltration rates when thoroughly wetted.

Bexar, Wilson, Karnes and Goliad counties have high concentration of Group C and D soils (Figure 2-1). Group C and D soils are characterized by relatively low percolation rates and could present additional challenges for infiltration. Generalized soil maps produced by the NRCS can provide guidance on soil characteristics but infiltrating rain gardens have been used successfully in areas of Bexar County with soil labeled hydrologic soil group D. Areas with C and D soils require careful attention and often some variations to the typical standards for designing and implementing LID BMPs; underdrains or soil amendments could be required to increase infiltration or allow for filtration through a soil media, as discussed in Appendix B.

2.1.2 Aquifer Recharge Zones

Groundwater plays an important role in both baseflow maintenance and water supply throughout the region. The Trinity, Edwards, Carrizo-Wilcox, Queen City/Sparta and Yegua-Jackson aquifers all have recharge zones that outcrop at the surface. The Edwards Aquifer is particularly sensitive to surface water quality due to the fractured nature of the limestone that makes up the recharge and artesian zones (Figure 2-2). The limestone typically is covered by less than six inches of soil that can contain high fractions of clay. The permeability of the soils and the underlying rocks are highly variable depending on the site and proximity to faults and solution features. The TCEQ requires identification of sensitive features within the Edwards Aquifer Recharge Zone to protect both endangered species and water quality; current TCEQ regulations for the Edwards Aquifer are discussed in [Section 2.2](#). LID features that typically use infiltration (e.g., bioretention areas and

permeable pavements) should be designed with groundwater protection in mind to ensure that pollutants are not concentrated in BMPs and transported into the aquifer. Details regarding the design of BMPs in sensitive groundwater areas are provided in Appendix B.

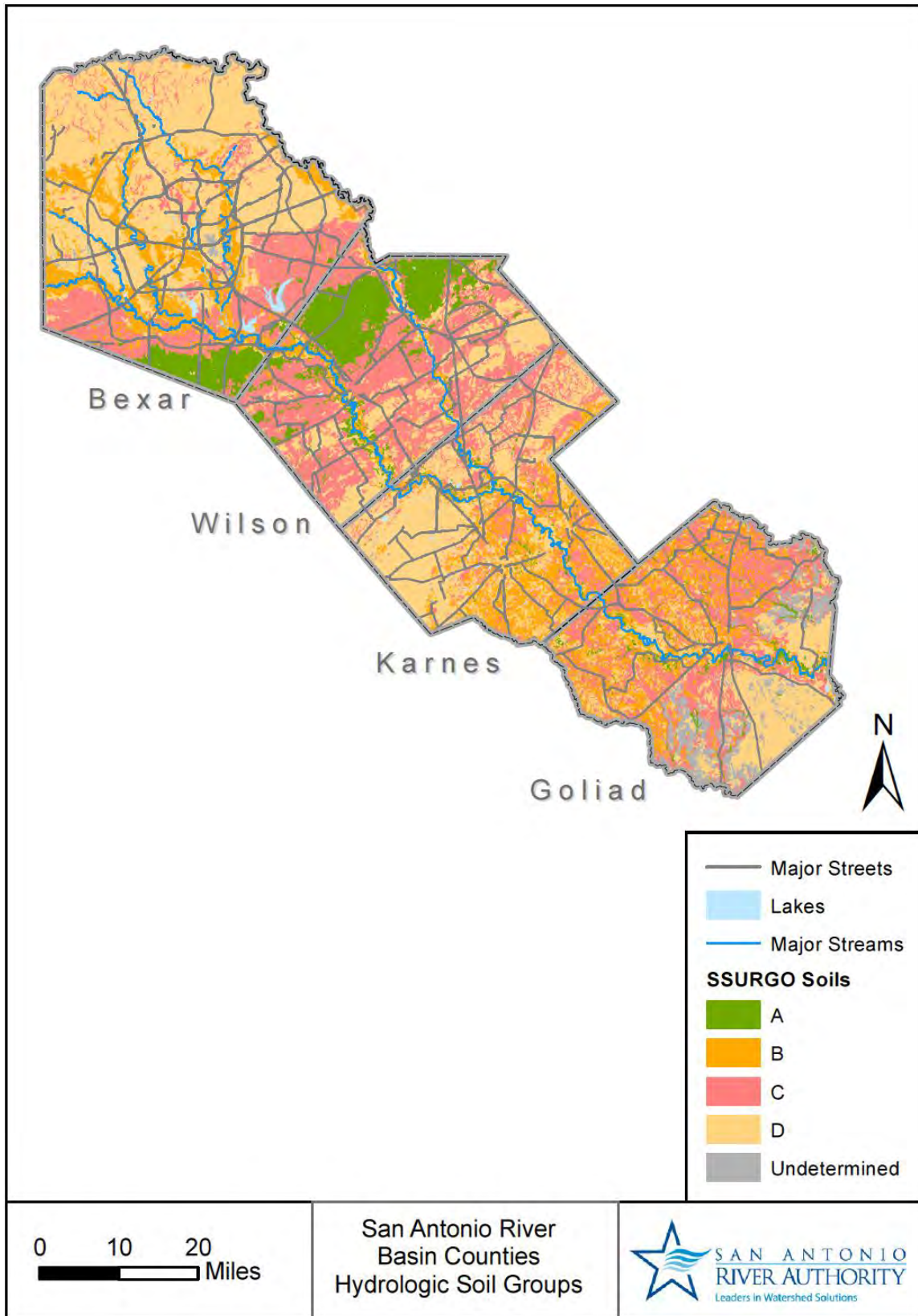


Figure 2-1. Hydrologic soil groups for San Antonio River Basin

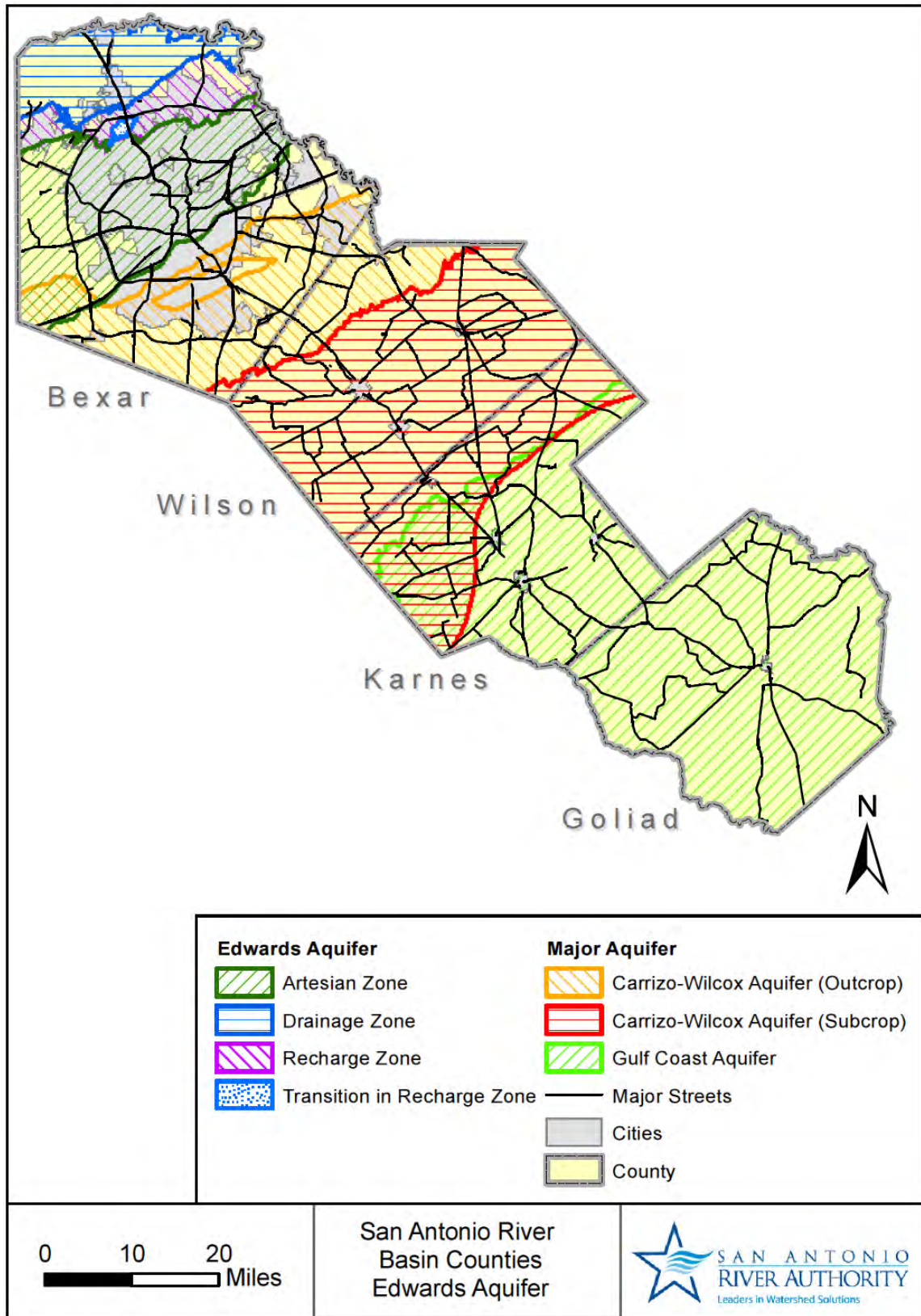


Figure 2-2. Artesian, drainage, recharge, and transition zones of the San Antonio River Basin

2.1.3 Eco-Regions and the Impact on LID Implementation

The five ecoregions in the SARB help guide LID design decisions by integrating hydrology, geology, soil types, rainfall patterns, and plant communities. Consideration of the different landscape characteristics assists in items as preliminary as BMP placement or choice, to farther reaching items such as long-term maintenance. For example, residential development in the Edwards Plateau would require minimizing development near karst topography and riparian river crossings due to limited soil layers and steep slopes that increase erosion possibilities and pose a threat to water quality. Additionally, from a regulatory standpoint, implementation of LID in certain portions of the Edwards Plateau will require design modifications as described later. In areas that have deeper soil profiles and gentler slopes, such as the Post Oak Savannah of Wilson and Goliad counties, infiltration rates vary from that of the nearby Edwards Plateau eco-region. A large swath of south Bexar County and northern Wilson contain sandy, HSG A soils covered by Post Oak trees that are sensitive to prolonged inundation and soil compaction. Appropriate species selection should also be considered for each of the ecoregions, particularly when using native soils or reestablishing native plant communities in previously cleared areas. The plant list in Appendix E includes vegetation appropriate for all five eco-regions in the SARB.

2.1.4 Climatology and Topography

The Hill Country and Coastal Plains experience very intense rainfall events that produce flashy, high volume floods. LID designs must incorporate energy dissipation, flow transition and bypass features to handle extreme events without causing excessive damage. In areas of steep slopes (Figure 2-3), LID practices require more assessment and careful design. BMP options include terracing of bioretention features, using rock berms to spread flow, permeable pavements that collect and infiltrate water, and site planning to avoid steep slopes. A series of level bioretention areas down a slope will calm flows and allow stormwater to pond temporarily behind internal control features before flowing to the next treatment area (Figure 2-4). Similarly, natural channel design techniques that use step-pool type design can provide designed grade control features that reduce erosion potential and transition water into riparian areas. Level spreaders, plunge pools, and vanes can be used to control velocity and energy dissipation prior to discharge from a collection system or BMP into conservation areas. The City of San Antonio's Tree Preservation ordinance (UDC Sec. 35-523) includes steep slopes as part of the definition of environmentally sensitive areas that require protection of native landscape and plant life through tree canopy preservation.

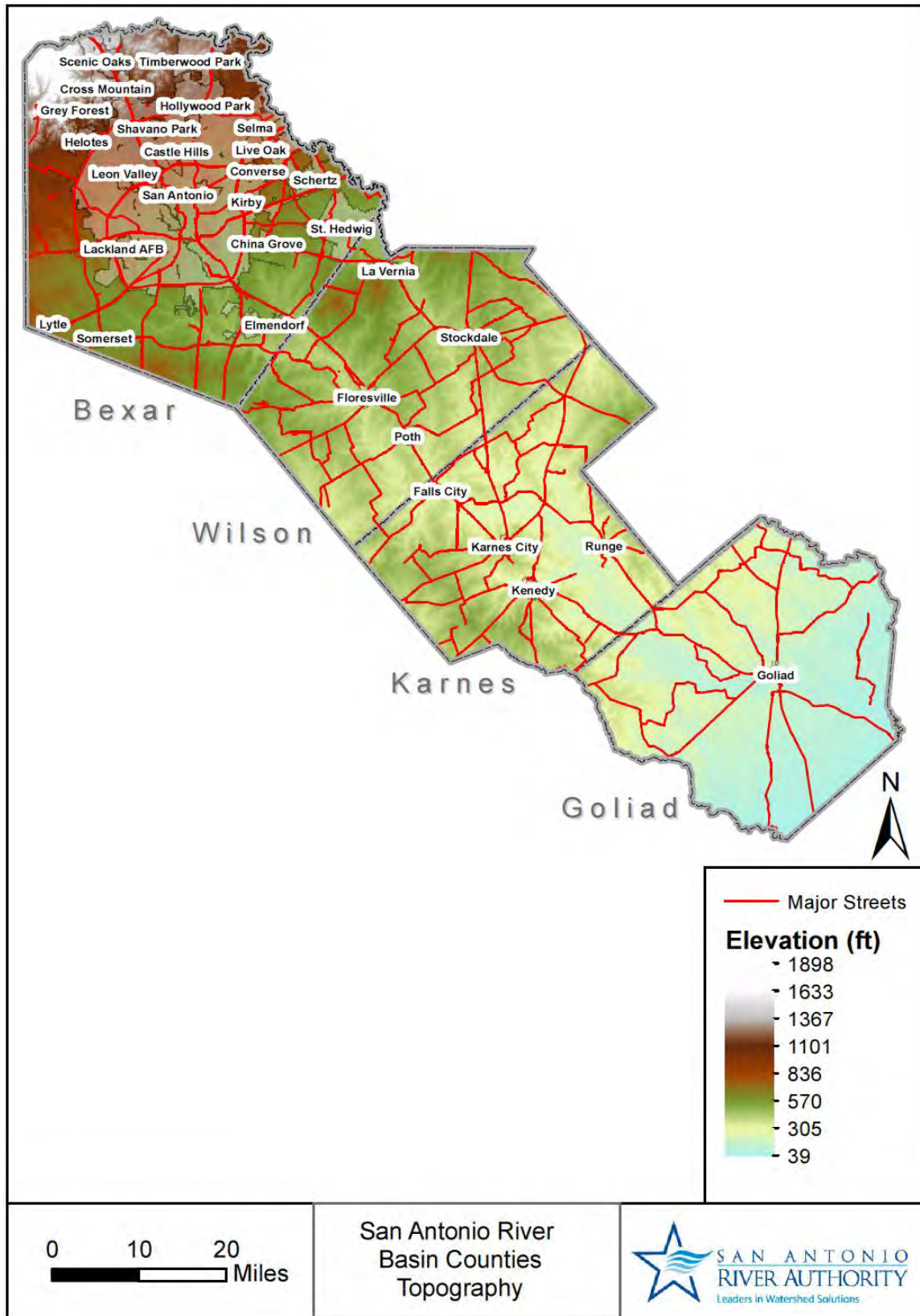


Figure 2-3. Topography of the San Antonio River Basin

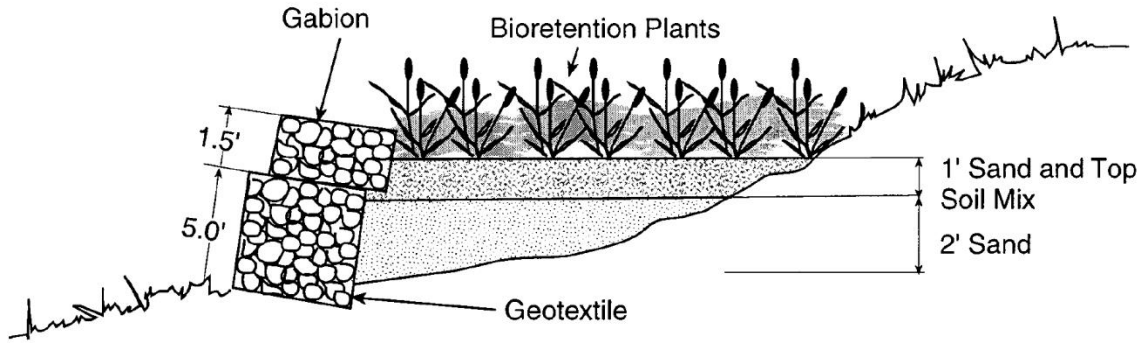


Figure 2-4. Schematic showing the cross section of a bioretention terrace suitable for use on slopes 10-20% (NCDENR 2009)

2.2 Relevant Federal and State Regulations and Guidelines

Stormwater management is guided by local regulations and guidance as well as federal and state regulations. The following sections describe federal and state regulations, and local regulations and guidance are presented in Appendix G.

2.2.1 National Pollutant Discharge Elimination System Stormwater Regulations

The local cities' and Bexar County's requirements for development projects to implement stormwater BMPs is based on section 402 (p) of the Clean Water Act. The Clean Water Act amendments of 1987 established a framework for regulating storm water discharges from municipal, industrial, and construction activities under the National Pollutant Discharge Elimination System (NPDES) program. Under the Clean Water Act, municipalities of sufficient size throughout the nation are issued a Municipal NPDES Permit. The primary goal of the permit is to stop polluted discharges from entering the municipally owned storm water conveyance system (the Municipal Separate Storm Sewer System, or MS4), and thus local receiving and coastal waters. The U.S. EPA is currently reviewing and updating MS4 permits with the goal of establishing measurable performance standards for stormwater management under the NPDES program. Potential MS4 permit revisions may focus on regulation of stormwater volume (particularly from high-frequency storm events) from development and redevelopment activities; as such, LID will likely serve a critical role in satisfying volume-based performance standards. TCEQ- 30 Texas Administrative Code (TAC) 213.5

The Edwards Aquifer rules protecting water quality are implemented through the TCEQ. Permanent BMPs are required for regulated activities that have the potential for polluting the Edwards Aquifer and hydrologically connected surface streams. Regulated activities generally apply to any development with more than 20% impervious cover including public infrastructure projects such as roadways and utilities. Development is required to mitigate 80% of the increase of total suspended solids (TSS) from existing to proposed conditions. This goal is more tailored than the broader LID goals that also address hydromodification, nutrients, and metals.

The typical BMPs approved by the TCEQ are listed in Table 2-1, but sand filters are the primary BMP currently used in the region. No retention facilities or pervious pavement without an impermeable liner are allowed over the recharge zone to discourage the infiltration of pollutants. Although this limitation must be understood prior to site assessment for infiltration BMPs in the recharge zone, LID BMPs can be adapted for use in all Edwards Aquifer Zones.

Table 2-1. Summary of BMPs Approved by TCEQ (2005)

BMPs	Does it Remove 80% TSS?	Is it in the TCEQ Technical Guidance Manual?	Is it Cost Effective?
Permanent BMPs			
Vegetative Filter Strip	Yes	Yes	Yes
Extended Detention Pond	No	Yes	Yes
Bioretention	Yes	Yes	Yes
Infiltration	Yes	No	Yes
Sand Filters	Yes	Yes	Yes
Wet Basins	Yes	Yes	Maybe
Constructed Wetlands	Yes	Yes	Maybe
Retention/Irrigation	Yes	Yes	Yes if water needed
Stormwater Credits			
Porous Pavement	Variable	Yes	Maybe
Rainwater Harvesting	Yes	No	Yes
Soil Amendment and Conservation Landscaping	Yes	No	Yes
Roof-top Disconnection	Yes	No	Yes
Natural Area Preservation	Yes	Yes	Yes

2.3 Incorporating LID in Capital Improvement Projects

Although this manual can guide engineers, architects, landscape architects, and project managers in a wide variety of private projects, many opportunities exist to incorporate LID practices into municipal capital improvement projects (CIPs). CIPs typically include infrastructure improvements such as developing roads and bridges, renovating municipal buildings, and enhancing parks and open space. An increasing number of CIPs are designed to incorporate LID BMPs to serve as pilot projects for local municipalities. As an example, Figure 2-5 shows conceptual renderings of the Hemisfair Complete Streets concept for Alamo Street.

With proper planning, LID design alternatives can be incorporated into such CIPs to minimize site disturbance, protect the hydrology of native, natural areas such as ephemeral wetlands, and use key hydrologic features such as flow path directions (see [Section 1.5](#) for LID site design principles and [Chapter 3](#) for LID BMP options).

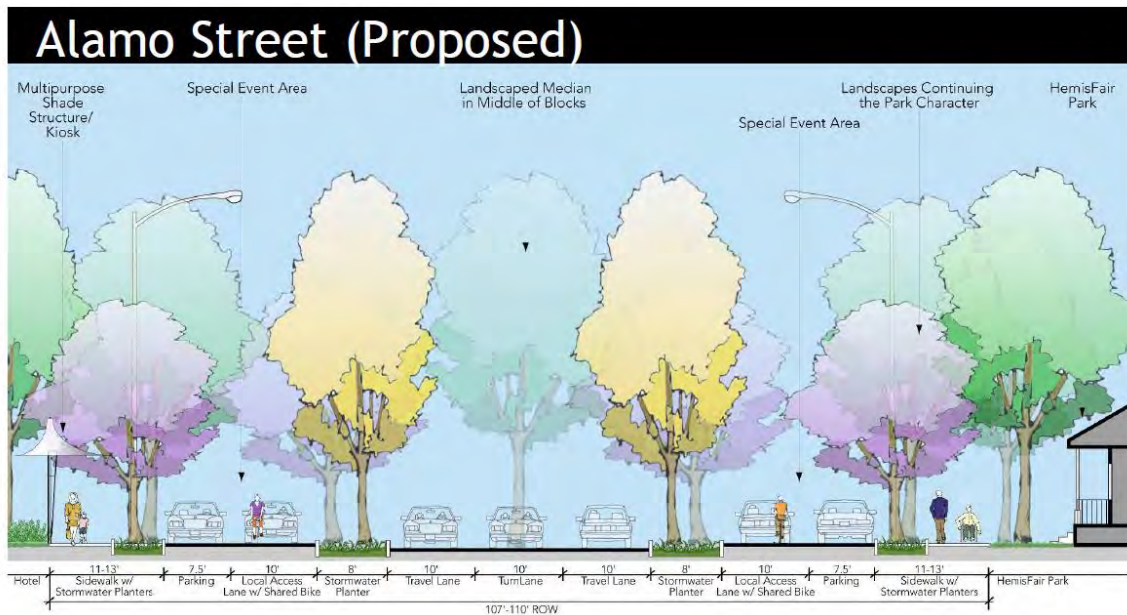


Figure 2-5. Cross-section rendering of the HemisFair Complete Streets concept for Alamo Street.
 Source: www.hemisfair.org

Ultimately, incorporating LID into CIPs can minimize site runoff, enhance water quality, and assist in regulatory compliance. In most municipalities, planning and designing CIP projects tend to be a collaboration of multiple departments such as Engineering and Capital Projects Department, Streets Division, Environmental Services, Planning Division and the Stormwater Department. To maintain adequate focus on meeting the required storm water management needs, such collaboration requires strong inter-departmental communication, well-established goals and objectives, and clear technical guidance to all involved; this *San Antonio River Basin Low Impact Development Technical Design Guidance Manual* is meant to provide such guidance. Specifically, the site assessment process described in [Section 1.5](#) is crucial for proper CIP site design. Additionally, technical details, renderings of example LID applications, and specific design steps are offered in Appendix B to provide guidance with incorporating LID into CIPs.

2.4 References

- Griffith, G.E., S.A. Bryce, J.M. Omernik, J.A. Comstock, A.C. Rogers, B. Harrison, S.L. Hatch, and D. Bezanson. 2004. Ecoregions of Texas. Two-sided color poster with map, descriptive text, summary tables, and photographs. U.S. Geological Survey, Reston, VA. Scale 1:2,500,000.
- NCDENR (North Carolina Department of Environment and Natural Resources). 2009. Chapter 12 Bioretention. NCDENR Stormwater BMP Manual. July 24, 2009. Raleigh, NC. <http://portal.ncdenr.org/web/wq/ws/su/bmp-ch12>
- TCEQ (Texas Commission on Environmental Quality). 2005. Complying with the Edwards Aquifer Rules—Technical Guidance on Best Management Practices. RG-348 (Revised) with Addendum. Texas Commission on Environmental Quality, Austin, TX <http://www.tceq.texas.gov/field/eapp>.
- TPWD (Texas Parks and Wildlife Department). No date. Edwards Plateau Ecological Region. http://www.tpwd.state.tx.us/landwater/land/habitats/cross_timbers/ecoregions/edwards_plateau.phtml. Accessed February 14, 2013.

3. LID Selection – Structural BMPs

Structural BMPs are implemented to capture, infiltrate, filter, and treat stormwater runoff from a project area to meet the required level of controls in terms of water quality and quantity. Selecting the appropriate BMP for a project area should be based on site-specific conditions and stormwater control targets. Selected BMPs should be sized to capture and treat the design storm according to the numeric sizing requirements for treatment control BMPs that are presented in Appendix A. A general description for each BMP is presented in this chapter. For a more detailed description and design specifications for each BMP, see Appendix B.

3.1 Selecting Structural BMPs

Selecting the proper BMP type and location depends on site-specific precipitation patterns, soil characteristics, slopes, existing utilities, and any appropriate setbacks from buildings or other infrastructures as determined in Step 1 of [Section 1.6.1](#). Further, selecting applicable and feasible BMPs will depend on the type of project, its characteristics, and the planning elements associated with the location of the project.

A general checklist for characterizing drainage areas and BMPs is below.

Drainage Area Characterization

- Total drainage area
- Percent imperviousness: total and directly connected
- Soil characteristics
- Known/expected runoff water quality constituents
- Depth to seasonal high water table and bedrock
- Topography, slope
- Land cover and land use (existing and future)
- Utilities
- Development history and existing buildings
- Storm drainage systems, location of outfalls
- Projected roadway alignment modifications, roadway expansion
- Rainfall records and statistical analysis of storm characteristics and frequency

BMP Characterization

- Type of BMP
- BMP surface area
- Surrounding soil characteristics
- Depth to water table
- Design target(s) according to any combination of volume, flow, or water quality control criteria
- Inlet and outlet features
- Primary stormwater treatment unit process

A BMP selection matrix based on the potential function and configuration of each BMP is presented in [Section 3.7](#). The function and configuration that dictate BMP selection include drainage area size and land use, available site area for BMP implementation, slope, depth to seasonal high water table and bedrock, soil characteristics and infiltration rates, setbacks, and pollutant reduction potential.

3.2 BMP Sizing

LID BMPs are typically sized to manage runoff from frequent smaller storm events (typically in the range of one to two inches over 24 hours). The size of a BMP should be established using the characterization of the drainage area and local hydrology. BMPs should be designed by applying either volume- or flow-based design criteria. Further details regarding BMP sizing and example calculations are in Appendix A. To determine the sizes for BMPs within treatment train, sizing calculations have been adapted as discussed in [Section 3.8](#).

3.3 Infiltration BMP's

The objectives of stormwater BMPs are first to slow and filter runoff using natural features. Infiltration and evapotranspiration, along with retention for reuse, offer additional benefits of the BMPs. Identifying and selecting BMPs on the basis of the pollutant(s) of concern is a function of site constraints, properties of the pollutant(s) of concern, BMP performance, stringency of permit requirements, and watershed-specific requirements such as TMDLs or Watershed Protection Plans. Pollutants of concern are especially important in water quality-limited stream segments and must be carefully reviewed in relationship to unit processes and potential BMP performance. Targeted constituents can include sand, silt, and other suspended solids; trash; metals such as copper, lead, zinc; nutrients such as nitrogen and phosphorus; pathogens; and organics such as petroleum hydrocarbons and pesticides. Table 3-1 indicates the major or dominant unit processes used for pollutant removal and secondary and optional processes based on designs of BMPs that incorporate those unit processes (Claytor and Schueler 1999). The BMP selection approach may also be used to assist in identifying BMPs for treatment trains. To improve performance, the designer should consider including different unit processes to address the constituents of concern. An optimal treatment train approach is provided in Appendix B to support this effort.

Table 3-1. Water quality unit processes for pollutant removal

Pollutants	Removal processes					
	Settling	Filtration/ straining	Absorption/ Adsorption	Bioaccumulation	Biotransformation/ phytoremediation	Other (e.g., photolysis; volatilization)
Sediment	●	●	○	○	○	○
Total Nitrogen	●	◐	◐	(◐)#	●	○
Total Phosphorus	●	◐	●	(◐)#	○	○
Trash	●	●	○	○	○	◐
Metals	●	○	●	●	●	○
Bacteria	●	(●)	○	●	● &	● *
Oil and grease	○	●	●	◐	●	●
Organics	●	◐	◐	●	●	●

BMPs often provide multiple unit processes, depending on design. Table 3-2 shows the removal processes for each BMP type including the major functions, followed by secondary and possible optional unit operations, depending on design (Claytor and Schueler 1999). BMPs can be used singularly or in series with multiple BMP types integrated as management practices to achieve the desired level of pollutant removal. Using a combination of BMPs with multiple treatment processes in one system is called a treatment train. Meeting targeted treatment objectives can usually be achieved using a series of stormwater treatment systems in a treatment train. That approach can apply to new designs and in retrofitting existing BMPs and sites. Such systems can often be designed along rights-of-way, in parking lots, or incorporated into landscaped areas to fit in relatively small or long, linear areas.

BMPs can be used singularly or in combination, or shared by multiple drainage areas, pursuant to local regulatory criteria (depending on project location and its jurisdiction), as outlined in Chapter 2.

Table 3-2. Hydrologic and water quality unit processes for BMPs

Structural BMPs	Hydrologic controls			Removal processes					
	Storage/detention or flow attenuation	Infiltration	Evapotranspiration	Settling	Filtration	Sorption	Bioaccumulation	Biotransformation/phytoremediation	Other (e.g., photolysis; volatilization)
<i>Infiltration BMPs</i>									
Bioretention	●	(●)	◐	◐	●	◐	●	●	(◐)
Bioswale	(●)	(●)	◐	◐	◐	◐	◐	◐	(◐)
Permeable pavement	●	(●)	○	●	◐	(◐)	○	◐	○
<i>Filtration BMPs</i>									
Planter boxes	●	(●)	◐	◐	●	◐	(●)	(●)	(◐)
Green roofs	(●)	○	●	◐	○	○	(◐)	(◐)	○
Sand filter	◐	(◐)	○	○	●	(◐)	○	○	(◐)
<i>Volume-Storage and Reuse BMPs</i>									
Cisterns/rain barrels	●	○	○	<i>Treatment typically provided by downstream BMP</i>					
Stormwater wetlands	(●)	○	◐	●	●	◐	●	●	(◐)
Extended Detention Basin	●	(◐)	◐	●	◐	◐	(◐)	◐	◐
<i>Conveyance and Pretreatment BMPs</i>									
Vegetated filter strip	○	●	●	◐	◐	◐	○	○	○
Vegetated swale	(◐)	(◐)	◐	●	●	○	○	○	○

An example of how BMPs can be implemented in combination to provide the maximum potential treatment for a site configuration include a treatment train utilizing vegetated filter strips draining to a vegetated swale that then conveys the stormwater to a bioretention area where stormwater is infiltrated or filtered through a soil media. An example of a treatment train is shown in Figure 3-1. Such a treatment train can be integrated into the site to maximize hydrologic and water quality treatment using the unit processes of each BMP type. Effectiveness of individual or multiple integrated practices can be compared in terms of removing substances or groups of pollutants. Water quality performance data from multiple sources is presented for each BMP type in [Section 3.4](#). Typical sources present an average of water quality performance data collected from multiple storm events over a multi-year period. BMPs sized to treat the volume produced by wet weather events will have the capacity to treat the smaller volume produced by dry weather flow with the same water quality performance. Water quality data is typically a combination of effluent and overflow samples.



Figure 3-1. Treatment train featuring a vegetated filter strip pretreating stormwater runoff before entering a grassed bioretention area, Raleigh, North Carolina. Source: Tetra Tech

When no specific pollutant has been targeted for removal, regulators should work with designers to address pollutant removal through flow- or volume-based requirements or both. Under such circumstances, cost may become the most important deciding factor in BMP selection rather than pollutant removal performance.

3.3.1 Bioretention

Bioretention areas are landscaped, shallow depressions that capture and temporarily store stormwater runoff. Bioretention areas are the most commonly implemented LID technique because they mimic predevelopment hydrologic conditions, enhance biodiversity and water quality, and can be easily incorporated into both new and existing development (Davis et al. 2009). Runoff intercepted by the practice is temporarily captured in shallow, vegetated depressions then filtered through the soil (often engineered soil) media. Pollutants are removed through a variety of physical, biological, and chemical treatment processes. Bioretention areas usually consist of a pretreatment system, surface ponding area, mulch layer, and planting soil media. The depressed area is planted with small- to medium-sized vegetation including trees, shrubs, and groundcover that can withstand urban environments and tolerate periodic inundation and dry periods. Plantings also provide habitat for beneficial pollinators and aesthetic benefits for stakeholders and can be customized to attract butterflies or particular bird species. Ponding areas can be designed to increase flow retention and flood control capacity. Bioretention areas are well suited to the San Antonio region because they can be adapted to a variety of site constraints and take advantage of the semi-arid climate for evapotranspiration. Advantages and limitations of bioretention areas are outlined below in Table 3-3.

Table 3-3. Advantages and limitations of bioretention areas

Advantages	Limitations
<ul style="list-style-type: none"> • Efficient removal of suspended solids, heavy metals, adsorbed pollutants, nitrogen, phosphorus, and pathogens • Can effectively reduce peak runoff rates for relatively frequent storms, reduce runoff volumes, and recharge ground water if soil conditions allow • Flexible to adapt to urban retrofits • Applicable for use in recharge zones, karst, expansive clays, and hotspots when properly designed with impermeable liners and underdrains • Well suited for use in small areas, and multiple, distributed units can provide treatment in large drainage areas • Can be integrated naturally into landscaping to enhance aesthetics and provide habitat • Standing water only present for 12-24 hours to minimize vector control concerns 	<ul style="list-style-type: none"> • Surface soil layer will require restoration if clogged over time • Frequent trash removal might be required, especially in high-traffic areas • Vigilance in protecting native soils from compaction during construction is essential • Single units can serve only small drainage areas • Requires maintenance of plant material and mulch layer

3.3.1.1 Hydrological Functions

Temporary surface storage is provided in a shallow basin to accommodate the capture of runoff from the drainage area. The captured runoff infiltrates through the bottom of the depression and a layer of planting soil, approximately 2 to 4 feet deep, that has an infiltration rate capable of draining the bioretention area within a specified design drawdown time (usually surface water should draw down in 12–24 hours, and subsurface water should drain in 48–72 hours (Davis et al 2009; Hunt and Lord 2006).

After the stormwater percolates through the soil media, it infiltrates into the underlying subsoil if site conditions allow for adequate infiltration rates (typically greater than 0.5 in/hr). The volume-reduction capability of bioretention areas can be enhanced by providing a gravel drainage layer beneath the bioretention area. When subsoil infiltration rates are slower than 0.5 in/hr, filtered water is directed toward a stormwater conveyance system or other BMP via underdrain pipes. Volume reduction via partial infiltration and storage in the soil (approximately 20 to 70 percent, depending on soil conditions) can still occur when underdrains are present as long as an impermeable liner is not installed (Davis et al. 2012); partial infiltration occurs in those cases because some of the stormwater bypasses the underdrain and percolates into the subsoil (Strecker et al. 2004; Hunt et al. 2006; Davis et al. 2012). Volume reduction can be enhanced by treating the subgrade with scarification, ripping, or trenching (as discussed in Appendix B.1.2.1; Tyner et al. 2009; Brown and Hunt 2010). Additionally, underdrains can be modified to create a sump or IWS zone which enhances stormwater volume and pollutant load reduction, while maintaining an aerated root zone for plant health (Brown and Hunt 2011).

Where conditions altogether prevent infiltration (such as in the Edwards Aquifer Recharge Zone, karst geology, or near building foundations), bioretention areas should be lined with an impermeable barrier (see [Section 2.1.2](#) for Edwards Aquifer zone delineations). Moderate volume reduction can still be achieved by lined systems because significant stormwater volumes can be

stored in the available pore space of the media to be used by vegetation between storm events (Li et al. 2009; Davis et al. 2012).

Bioretention areas are typically planted with grasses, shrubs, and trees that can withstand short periods of saturation (i.e., 12–72 hours) followed by longer periods of drought. In addition to transpiring significant stormwater volumes, vegetation can enhance pollutant removal, reduce soil compaction, and provide ecological and aesthetic value (Hatt et al. 2009; Li et al. 2009; Barrett et al. 2013). Vegetation adapted to the San Antonio region is preferable for use in bioretention areas because native ecotypes, such as prairie grasses and forbs, can typically tolerate extreme hydroperiods and can promote infiltration and evapotranspiration with their deep root systems. Bioretention vegetation can be specified to mimic predevelopment communities while being aesthetically pleasing. IWS is recommended to improve soil moisture retention and plant survival in the San Antonio region (Li et al. 2010; Barrett et al. 2012; Houdeshel et al. 2012). A plant list to guide vegetation selection is located in Appendix E.

Bioretention areas are designed to capture a specified design volume and can be configured as online or offline systems. Online bioretention areas require an overflow system for passing larger storms. Offline bioretention areas do not require an overflow system but do require some freeboard (the distance from the overflow device and the point where stormwater would overflow the system). Bioretention can also be designed for peak flow mitigation to satisfy local requirements. Controlled experiments in Texas demonstrated reductions in peak discharge from fully lined (non-infiltrating) bioretention cells with as little as 2 feet of filter media (Li et al. 2010). Peak attenuation is most effectively achieved by infiltrating practices with high surface storage and media pore volume, and by pairing bioretention in a treatment train with a detention-type BMP (Hunt et al. 2012; Davis et al. 2012; Brown et al. 2012).

3.3.1.2 Water Quality Performance

Bioretention areas remove pollutants at various depths through physical, chemical, and biological mechanisms. Specifically, they use absorption, microbial activity, plant uptake, sedimentation, and filtration. Bioretention areas provide relatively consistent and high pollutant removal for sediment, metals, and organic pollutants (e.g., hydrocarbons). Most sediment removal occurs in pretreatment practices, in the mulch layer, and in the top 2 to 8 inches of soil media (Hatt et al. 2008; Li and Davis 2008; Stander and Borst 2010). The Texas Commission on Environmental Quality (TCEQ) recommends bioretention for compliance with the sediment removal requirements of the *Complying with the Edwards Aquifer Rules: Technical Guidance on Best Management Practices* (TCEQ 2005). Metals are commonly sediment-bound and are removed in the top 8 inches of media (Hsieh and Davis 2005; Hunt et al. 2012).

Nitrogen and phosphorus removal is less consistent. Total phosphorus percent removal has been found to vary between a 240 percent increase (production) and a 99 percent decrease (removal). The significant increase is suspected to be the result of excessive phosphorus levels in the furnished soil media (Hsieh and Davis 2005; Hunt et al. 2006; Davis 2007). Greater total phosphorus removal can be achieved by using soil media with total phosphorus concentrations below 15 parts per million (ppm) (Hunt and Lord 2006). A study in Texas indicated that nutrient export can also occur when bioretention soils are amended with excessive compost (Li et al. 2010). Nitrate removal has been found to vary between a 1 and 80 percent decrease (Kim et al. 2003; Hunt et al. 2006). Total Kjeldahl nitrogen (TKN) has been found to vary between a 5 percent increase and 65 percent decrease (Kim et al. 2003; Hunt and Lord 2006). Greater nitrate and TKN removal can be achieved

by reducing the infiltration rate in the planting soil to 1–2 in/hr and ensuring that the soil media is at least 3 feet deep (Hunt and Lord 2006). Nitrate removal can be improved by incorporating a saturated layer in the soil media to promote anaerobic conditions for denitrification (Kim et al. 2003; Hunt and Lord 2006; Passeport et al. 2009). Additionally, studies performed in Texas demonstrated significantly improved nutrient reduction efficiency, relative to unvegetated filters, when bioretention soil was planted with a native prairie grass (Barrett et al. 2012).

Several streams in the San Antonio region (including the Upper and Lower San Antonio River) are impaired by bacteria for contact recreation and high aquatic life use (TCEQ 2007, 2008). Bioretention represents a technology to mitigate pathogens from urban watersheds (especially when volume reduction is considered), although limited data exist for bacteria, virus, and protozoa removal. Most scientists and engineers agree that bacteria die-off occurs at the surface where organisms are exposed to solar radiation and dry (desiccating) conditions; dense vegetation in the bioretention area can limit the penetration of sunlight, but it can provide habitat for bacterivores and other beneficial pathogen predators (Hunt and Lord 2006; Hunt et al. 2008; Hathaway et al. 2009). Microbes are also sequestered by sedimentation and sorption; therefore, 2 feet minimum media depth and slower infiltration rates (1–2 in/hr) are recommended to enhance pathogen removal (Hathaway et al. 2011; Hunt et al. 2012).

In addition to chemical and biological pollutant removal, bioretention can be designed to reduce thermal loading to waterways. Thermally enriched runoff can increase stream temperatures and have adverse impacts on stream biota and dissolved oxygen (Booth et al. 2013; USEPA 1986). Research suggests that deep media beds (generally four feet or greater) can buffer extreme temperatures and that infiltration of stormwater can decrease overall thermal loading (Hunt et al. 2012; Jones and Hunt 2009; Winston et al. 2011; Wardynski et al. 2013). Thermal mitigation can likely be enhanced by shading bioretention areas with tree canopy cover and including IWS (Hunt et al. 2012; Jones et al. 2012). The depths where typical pollutant removal occurs are shown in Figure 3-2.

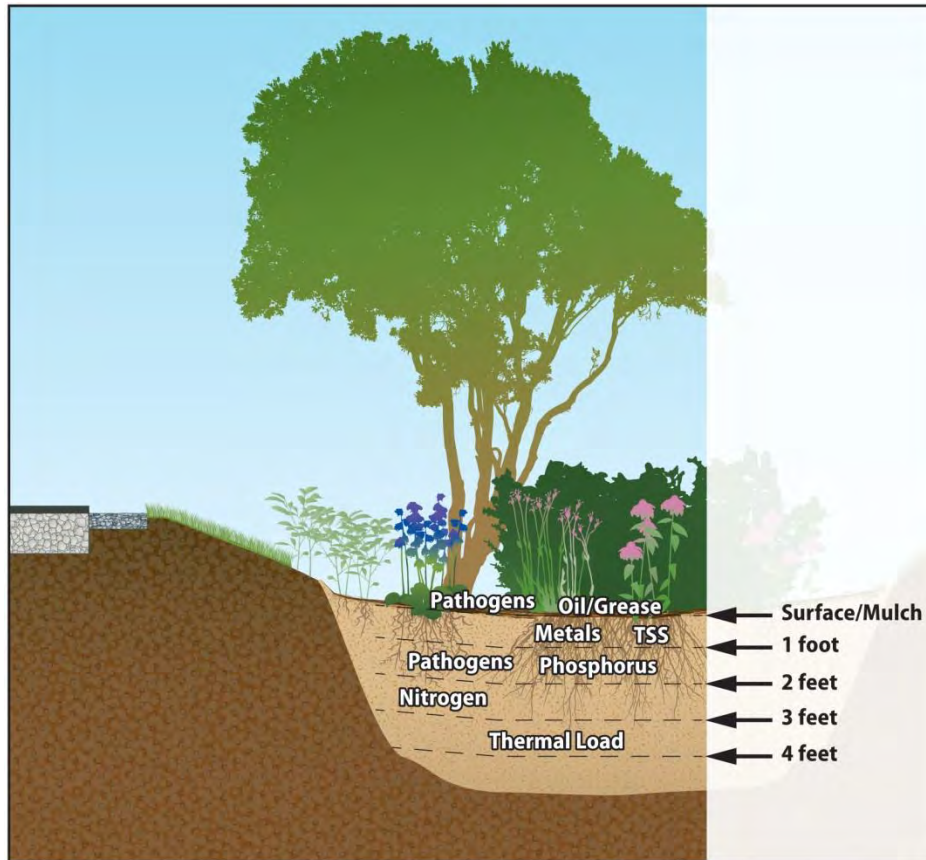


Figure 3-2. Schematic showing pollutant removal depths in a bioretention area

3.3.1.3 Applications and Configurations

Appendix B.1 outlines major design components and site considerations and describes the process for designing bioretention areas. Typical site applications and configurations are described further below.

3.3.1.4 Parking Lots

Bioretention areas can be used in parking lot islands or along the edge of the parking lot where water can be diverted into the bioretention area. Linear bioretention can also be used in the median areas between the parking spaces. Hydraulic restriction barriers should be installed and extended below adjacent pavement subgrades to protect pavement from water-induced structural issues (see Appendix B.11.6). Figure 3-3 and Figure 3-4 show examples of parking lot island bioretention areas.



Figure 3-3. Parking lot bioretention area, Los Angeles, California. Source: Tetra Tech



Figure 3-4. Bioretention system incorporated into parking lot, Mission Reach Operations Center, San Antonio, Texas.

3.3.1.5 Roads

Bioretention can also be integrated into the right-of-way of roads. Similar concepts apply to roads as to parking lots. Some pretreatment is required to remove large particles and slow the runoff to non-erosive flows. Impermeable liners must be installed to protect adjacent pavement from water-induced structural issues (see Appendix B.11.7). Bioretention can be used along the edge of roads, as shown in Figure 3-5, or in medians.



Figure 3-5. Rendering showing how roadside bioretention can be retrofit into the right-of-way to intercept street runoff through curb cuts, Broadway Street, Witte Museum, San Antonio, Texas. Source: Bender Wells Clark Design

Bioretention designs can be incorporated into the edge of roadways using traffic calming devices (e.g. curb extensions or “pop-outs”) and the grassed strip or other areas between the edge of the roadway and the sidewalk. Figure 3-6 shows an example of a rain garden incorporated into the same space where on-street parking is located.



Figure 3-6. Rain garden pop-out incorporated with on-street parking, River House, San Antonio, Texas.

For standard traffic calming and roadway specifications, see the street design specifications in the Texas Department of Transportation Roadway Design Manual (Texas Department of Transportation 2010). For additional guidance See Appendix G. Landscaping is often required or expected in traffic calming features, which can be converted to a bioretention area to treat stormwater runoff from the paved surfaces. The maximum width of the right-of-way, minimum allowable roadway width, and required sidewalk width should be considered when optimizing bioretention implementation in the roadside environment.

Further details and design templates for bioretention areas in the right-of-way are provided in Appendix C.

3.3.1.6 Residential and Commercial Landscape

Bioretention can also be integrated into the landscape of a site in open or common areas. Runoff can be routed into the bioretention areas from rooftops, sidewalks, or impervious areas on a site. Energy dissipation is important to prevent erosion in the bioretention area and is usually accomplished in tandem with pretreatment using a stabilized forebay inlet or a vegetated filter strip. When bioretention is integrated into landscapes, it is important to consider any effects that could be made to surrounding structures from infiltration. Figure 3-7 shows a bioretention area that was integrated into a building's common area used as open space.



Figure 3-7. Bioretention in a common area, Hector Garcia Middle School, San Antonio, Texas.

3.3.2 Bioswales

Bioswales are shallow, narrow, vegetated channels, often referred to as linear bioretention, that are designed to treat runoff primarily by vertical filtration of runoff through soil media and infiltration into underlying soils. Bioswales can serve as conveyance for stormwater and can be used in place of traditional curbs and gutters; however, when compared to traditional vegetated swale systems, **the primary objective of bioswales is infiltration and water quality enhancement rather than conveyance (except for excessive flow)**. Bioswales significantly vary in design configuration and can be constructed with or without check dams, subsurface storage media, and underdrains. Soil media, such as that used in bioretention areas, can be added to a bioswale to improve water quality, reduce the runoff volume, and modulate the peak runoff rate, while also providing conveyance of excess runoff. Advantages and limitations of bioswales are outlined in Table 3-4.

Table 3-4. Advantages and limitations of bioswales

Advantages	Limitations
<ul style="list-style-type: none"> • Efficient removal of suspended solids, heavy metals, adsorbed pollutants, nitrogen, phosphorus, and pathogens • Can effectively reduce peak runoff rates for relatively frequent storms, reduce runoff volumes, and recharge ground water if soil conditions allow • Flexible to adapt to urban retrofits including bordering parking lots and linearly along impervious surfaces • Well suited for use in small areas, and multiple, distributed units can provide treatment in large drainage areas • Can be integrated naturally into landscaping to enhance aesthetics • Can reduce need/cost for more traditional, subsurface conveyance strategies • Standing water only present for 12-24 hours, so minimal vector control concerns 	<ul style="list-style-type: none"> • Surface soil layer can clog over time (though it can be restored) • Frequent trash removal might be required, especially in high-traffic areas • Vigilance in protecting native soils from compaction during construction is essential • Single units can serve only small drainage areas • Require maintenance of plant material and mulch layer • Site slopes greater than 4% may limit application

3.3.2.1 Hydrologic Function

Bioswales share the same functions as bioretention areas in that they are vegetated and mulched or grassed (i.e., landscaped) shallow depressions that capture and temporarily store stormwater runoff but are designed to be narrow and linear to fit within certain site constraints. The captured runoff is temporarily stored on the surface then infiltrates through the bottom of the depression and a layer of soil media, approximately 2 to 4 feet deep, that has an infiltration rate capable of draining the bioretention area (to the bottom of the media) within a specified design drawdown time (usually 12 to 48 hours). The soil media provides treatment through filtration, adsorption, and biological uptake.

After the stormwater infiltrates through the soil media, it percolates into the underlying subsoil, if site conditions allow for adequate infiltration and slope protection (see Appendix B). If site conditions do not allow for adequate infiltration or slope protection, filtered water is directed toward a stormwater conveyance system or other BMP via underdrain pipes.

Bioswales are designed to capture a specified design volume and can be configured as online or offline systems. Online bioswales require an overflow system for passing larger storms. Offline bioswales do not require an overflow system but do require some freeboard (the distance from the overflow device and the point where stormwater would overflow the system).

If an underdrain is not needed because infiltration rates are adequate and slope is not a concern, the remaining stormwater passes through the soil media and percolates into the subsoil. Partial infiltration (approximately 20 to 25 percent, depending on soil conditions) can still occur when underdrains are present as long as no impermeable barrier is between the soil media and subsoil. Partial infiltration occurs in such cases because some of the stormwater bypasses the underdrain and percolates into the subsoil (Strecker et al. 2004; Hunt et al. 2006). Volume reduction can be further enhanced by including IWS and by treating the subgrade with scarification, ripping, or trenching (as discussed in Appendix B.1.2.1; Tyner et al. 2009; Brown and Hunt 2010).

Bioswales are typically planted with grasses, shrubs, and trees that can withstand short periods of saturation (12 to 72 hours) followed by longer periods of drought. Inclusion of IWS can improve soil water retention for plant survival.

3.3.2.2 Water Quality Performance

Bioswales are volume-based BMPs intended primarily for water quality treatment and, depending on site slope and soil conditions, can provide high volume reduction. Where site conditions allow, the volume-reduction capability can be enhanced for achieving additional credit toward meeting the volume-reduction requirement by omitting underdrains and providing a gravel drainage layer beneath the bioswale. Bioswales function similarly to bioretention areas and remove pollutants through physical, chemical, and biological mechanisms. Specifically, they use absorption, microbial activity, plant uptake, sedimentation, and filtration. Refer to [Section 3.3.1.2](#) for water quality performance details.

3.3.2.3 Applications and Configurations

Appendix B.2 outlines major design components and site considerations and describes the process for designing bioswales. Typical site applications and configurations are described further below.

3.3.2.4 Parking Lots

Bioswales are especially useful along the edge of parking lots or between facing parking stalls where narrow, linear space is available for stormwater treatment as seen in Figure 3-8. Pretreatment is important for parking lot areas to remove large sediments and to slow the runoff to non-erosive flow rates (1 in/hr for mulch and 3 in/hr for sod). Pretreatment typically consists of a gravel verge followed by turf.

3.3.2.5 Roads

Bioswales can also be integrated into the right-of-way and medians of roads. Similar concepts apply to roads as to parking lots. Some pretreatment could be required to remove large particles and slow the runoff to non-erosive flows. Bioswales can be used along the edge of roads or in medians.

For standard median and right-of-way specifications, see local street design standards. To allow space for bioswale implementation, new roads should be designed with the maximum right-of-way width and minimum curb-to-curb spacing.



Figure 3-8. Bioswale that receives stormwater runoff from a parking lot, City of San Antonio Development Services Department, San Antonio, Texas.

3.3.3 Permeable Pavement

Permeable pavement is a highly versatile stormwater BMP because it can effectively reduce pollutants and can be integrated into site plans with various configurations and components. Permeable pavement allows streets, parking lots, sidewalks, and other impervious covers to retain the infiltration capacity of underlying soils while maintaining the structural and functional features of the materials they replace. Permeable pavement has small voids or aggregate-filled joints that allow water to drain through to an aggregate reservoir. Stormwater stored in the reservoir layer can then infiltrate underlying soils or drain at a controlled rate via underdrains to other downstream stormwater control systems. Permeable pavement systems can be designed to operate as underground detention if the native soils do not have sufficient infiltration capacity, or if infiltration is precluded by aquifer protection, hotspots, or adjacent structures. Permeable pavement can be developed using modular paving systems (e.g., permeable interlocking concrete pavers, concrete grid pavers, or plastic grid systems) or poured in place solutions (e.g., pervious concrete or porous asphalt). Some pervious concrete systems can also be precast. In many cases, especially where space is limited, permeable pavement is a cost-effective solution relative to other practices because it doubles as both transportation infrastructure and a BMP. Advantages and limitations of permeable pavement are outlined in Table 3-5.

Table 3-5. Advantages and limitations of permeable pavement

Advantages	Limitations
<ul style="list-style-type: none"> • Replaces completely impervious surface options with partially impervious surfaces • Reduces stormwater runoff rate and volume • Reduces loads of some pollutants in surface runoff by reducing the volume of stormwater leaving a site • Reduces stormwater infrastructure footprint and promotes multi-benefit uses by using treatment area for parking/driving with possible cost reductions • Increases ground water recharge • Adaptable to urban retrofits • Many options available depending on specific site needs and aesthetics • Applicable for use in recharge zones, karst, expansive clays, and hotspots when properly designed 	<ul style="list-style-type: none"> • Potential for clogging of porous media by sediment, which could lead to reduced effectiveness without proper maintenance • Should not receive runoff from adjacent pervious surfaces with high sediment/debris yield • Typically not cost effective for high-traffic areas or for use by heavy vehicles (requires increased structural design and maintenance frequency) • Permeable pavement should be installed only by contractors qualified and certified for permeable pavement installation • Typically recommended for grades of 5% or less

3.3.3.1 Hydrologic Functions

Permeable pavement systems are designed to reduce surface runoff by allowing stormwater to infiltrate the pavement surface. While the specific design can vary, most permeable pavements have a similar structure consisting of a surface course layer and an underlying stone aggregate reservoir layer. Modular storage units, chambers, and pipes can also be integrated for additional subsurface storage. Where soils permit, permeable pavement allows captured runoff to fully or partially infiltrate into underlying soils; where infiltration is restricted (such as in the Edwards Aquifer Recharge Zone, karst, or near building foundations), permeable pavement can be lined with an impermeable membrane and used as detention systems.

Volume reduction primarily depends on the drainage configuration and subsoil infiltration capacities. Systems installed without underdrains in highly permeable soils can achieve practically 100 percent volume reduction efficiency (Bean et al. 2007). Systems installed in restrictive clay soils can still give significant volume reduction (Tyner et al. 2009; Fassman and Blackbourn 2010). The volume reduction can be further enhanced by treating the subgrade with scarification, ripping, or trenching (as discussed in Appendix B.5.2; Tyner et al. 2009; Brown and Hunt 2010), by omitting underdrains (where practicable), or by incorporating an internal water storage layer by upturning underdrain inverts to create a sump (Wardynski et al. 2013). Peak flow also can be effectively attenuated by permeable pavement systems by reducing overall runoff volumes, promoting infiltration, and increasing the lag time to peak discharge (Collins et al. 2008).

3.3.3.2 Water Quality Performance

Permeable pavement systems, when designed and installed properly, consistently reduce concentrations and loads of several stormwater pollutants, including heavy metals, motor oil, sediment, and some nutrients. The aggregate subbase provides water quality improvements through filtering and chemical and biological processes, but the primary pollutant removal mechanism is typically load reduction by infiltration into subsoils.

Pollutant-removal efficiencies for permeable pavements have been well studied. Permeable pavement systems consistently reduce sediment concentrations and loads; however, high loadings of TSS significantly reduce the functional life of permeable pavement systems because of clogging in the void space. TSS reductions have been shown to range from 32 to 96 percent, with average removal efficiency of 81 percent (MWCOG 1983; Schueler 1987; Pagotto et al. 2000; Rushton 2001; Gilbert and Clausen 2006; Bean et al. 2007; CWP 2007; Toronto and Region Conservation Authority 2007; Roseen et al. 2009, 2011; Fassman and Blackbourn 2011). TSS can be practically eliminated (100 percent reduction) when systems fully infiltrate captured runoff. Because phosphorus tends to be associated with sediment particles, total phosphorus reduction is fairly consistent, and removal efficiencies range from 20 to 78 percent (MWCOG 1983; Schueler 1987; Rushton 2001; Gilbert and Clausen 2006; Bean et al. 2007; CWP 2007; Toronto and Region Conservation Authority 2007; Roseen et al. 2009, 2011; Yong et al. 2011). As with phosphorus, sediment-bound metals are also reliably reduced; average removal efficiencies for cadmium, lead, zinc, and copper range from 65 to 84 percent (MWCOG 1983; Schueler 1987; Pagotto et al. 2000; Rushton 2001; Dierkes et al. 2002; Brattebo and Booth 2003; Gilbert and Clausen 2006; Bean et al. 2007; Toronto and Region Conservation Authority 2007; CWP 2007; Roseen et al. 2009, 2011; Fassman and Blackbourn 2011).

Nitrogen removal is more variable because permeable pavement does not typically provide the mechanisms for denitrification. Total nitrogen removal efficiency has been shown to range from –40 to 88 percent (MWCOG 1983; Schueler 1987; CWP 2007; Collins et al. 2010). High removal efficiencies have been reported for hydrocarbons (92–99 percent; Roseen et al. 2009, 2011). Permeable pavement has demonstrated mixed performance for reducing indicator bacteria counts from effluent (Myers et al. 2009; Tota-Maharaj and Scholz 2010); however, infiltrating systems could effectively reduce pathogen counts by filtering runoff through underlying soils and reducing the overall stormwater volume.

Similar to bioretention, research indicates that permeable pavement can be used to mitigate thermal loading to waterways by buffering extreme temperatures within the aggregate profile and by infiltrating runoff into subsoils (Wardynski et al. 2013).

3.3.3.3 Applications and Configurations

Appendix B.3 outlines major design components and site considerations and describes the process for designing permeable pavement. Typical site applications and configurations are described further below.



Figure 3-9. Porous asphalt parking lot, Mission Library, San Antonio Texas.

Parking Lots

Permeable pavement is typically used in a parking lot to provide a pervious alternative to a typically impervious area. The entire lot or only portions can be permeable; typically the parking stalls will be permeable and the driving lanes consist of standard paving. If a high level of traffic is anticipated regularly (such as in a drive-through) or heavy vehicles must pass through (such as garbage trucks) it may be cost effective to design the travel lane with standard paving materials and slope them toward the permeable parking stalls; however, permeable

pavements can be designed for heavy traffic loading by using abrasion resistant materials and by increasing the structural base layer depth. Figure 3-9 shows an example of the entire parking lot being permeable pavement, and Figure 3-10 shows only the parking stalls being permeable.

Sidewalks and Pedestrian Plazas

Permeable pavement can also be effective for pedestrian uses, and most types of permeable surface courses are ADA compliant. Sidewalks can be constructed of pervious pavement materials to reduce runoff in highly impervious areas. This can be effective in malls, plazas, promenades, and other outdoor hardscapes with low sediment loads. Care should be taken during site layout to allow for ease of maintenance (for details on maintaining permeable sidewalks, see [Section 4.3.5](#)). An example of permeable pavement in a pedestrian plaza is shown in Figure 3-11.

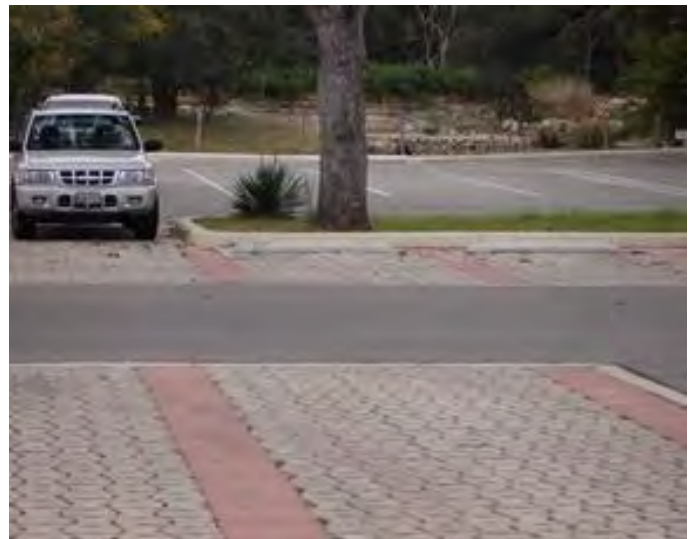


Figure 3-10. Permeable Interlocking Concrete Paver parking stalls, Oaks Business Park, San Antonio, Texas. Source: Bender Wells Clark Design



Figure 3-11. Permeable pavement pedestrian plaza, James Madison High School Agriscience Building, San Antonio, Texas. Source: Bender Wells Clark Design

Access Roads and Shoulders

Permeable pavement can also be used in areas that receive little traffic, such as fire lanes, shown in Figure 3-12, or vegetated shoulders for temporary parking. Most pavers are rated for loading of heavy vehicles such as fire trucks as long as sufficient structural base layers are provided.



Figure 3-12. Concrete grid pavers used in an emergency vehicle access lane, San Antonio River Authority Main Office, San Antonio, Texas.

3.4 Filtration BMPs

Filtration BMPs have been used widely because of their relatively small footprint and moderate physical requirements (FHWA 2002). Because of their versatility, filtration BMPs can be incorporated into a wide range of landscapes including roadway corridors, rights-of-way, sidewalks, and areas with limited space; certain filtration BMPs (e.g., sand filters) can also be implemented underground. Most filtration BMPs are designed to treat only a portion of a storm event, usually based on volume- or flow-based designs. Stormwater quality management is primarily provided by filtration, sedimentation, straining, and sorption as stormwater passes through small pore spaces. Filtration BMPs are not intended to infiltrate runoff into subsoils.

3.4.1 Planter Boxes

A planter box is a concrete box containing soil media and vegetation that functions similarly to a small bioretention area but is completely lined and must have an underdrain. Planter boxes have been implemented around paved streets, parking lots, and buildings to provide initial stormwater detention and treatment of runoff. Such applications offer an ideal opportunity to minimize directly connected impervious areas in highly urbanized areas. In addition to stormwater management benefits, planter boxes provide on-site stormwater treatment options, green space, and natural aesthetics in tightly confined urban environments. The vegetation and soil media in the planter box provide functions similar to bioretention area. Advantages and limitations of planter boxes are outlined below in Table 3-6.

Table 3-6. Advantages and limitations of planter boxes

Advantages	Limitations
<ul style="list-style-type: none"> • Efficient removal of suspended solids, heavy metals, adsorbed pollutants, nitrogen, phosphorus, and pathogens • Can effectively reduce peak runoff rates for the water quality design storm and reduce runoff volumes through evapotranspiration • Flexible to adapt to urban retrofits and are well suited for small, highly impervious, areas • Can be integrated naturally into landscaping to enhance aesthetics and provide multi-benefit use • Does not require a setback from structural foundations • No geotechnical limitations—can be used where infiltration is restricted (e.g., Edwards Aquifer Recharge Zone, clay soils) 	<ul style="list-style-type: none"> • Surface soil layer could clog over time (though it can be restored) • Frequent trash removal could be required, especially in high-traffic areas • Single units can serve only small drainage areas • Requires maintenance of plant material and mulch layer • Does not promote deep infiltration to supplement ground water recharge

3.4.1.1 Hydrologic Functions

Planter boxes are vegetated and mulched or grassed (i.e., landscaped), shallow depressions that capture, temporarily store, and filter stormwater runoff before directing the filtered stormwater toward a stormwater conveyance system or other BMP via underdrain pipes. The captured runoff infiltrates through the bottom of the depression and a soil media layer approximately 2 to 4 feet deep that has an infiltration rate capable of draining the planter box (to the bottom of the soil media) within a specified design drawdown time (usually 12 to 48 hours; Davis et al 2009; Hunt and Lord 2006). The soil media provides treatment through filtration, adsorption, and biological uptake.

Some volume reduction is possible through evapotranspiration and storage in the soil media. Planter boxes are typically planted with grasses, shrubs, and trees that can withstand short periods of saturation (12 to 24 hours; Davis et al 2009; Hunt and Lord 2006) followed by longer periods of drought.

3.4.1.2 Water Quality Performance

Planter boxes are volume-based BMPs intended, primarily, for water quality treatment that can provide limited peak-flow reduction for the water quality or design storm and volume reduction. Planter boxes should be used only in place of bioretention areas where geotechnical conditions do not allow for infiltration. Although planter boxes do not allow for infiltration into the subsoils, they still provide functions considered fundamental for LID practices. Research has shown that runoff volume can be reduced by as much as 15 to 20 percent by systems that are lined or completely contained (Hunt et al. 2006) through evapotranspiration. They are considered only as a last resort to provide some water quality treatment in areas where infiltration is not recommended.

Planter boxes remove pollutants through physical, chemical, and biological mechanisms. Specifically, they use absorption, microbial activity, plant uptake, sedimentation, and filtration, similar to bioretention areas. Planter boxes are capable of consistent and high pollutant removal for sediment, metals, and organic pollutants (e.g., hydrocarbons). Current research shows that pollutant removal is possible with underdrains through the function provided at the surface and by the soil media. Most of the sediment removal occurs in the top mulch layer, while metals removal commonly occurs in the first 18 inches of the soil media (Hseih and Davis 2005; Hunt and Lord 2006).

3.4.1.3 Applications and Configurations

Appendix B.4 outlines major design components and site considerations and describes the process for designing planter boxes. Typical site applications and configurations are shown below. Figure 3-13 shows how a planter box can be incorporated next to a building, and Figure 3-14 shows a planter box in an ultra-urban area.



Figure 3-13. Planter boxes along a building, San Diego, California. Source: Tetra Tech



Figure 3-14. Planter box in an ultra-urban setting, Philadelphia, Pennsylvania. Source: Tetra Tech

3.4.2 Green Roofs

Green roofs reduce runoff volume and rates by intercepting rainfall in a layer of rooftop growing media. Rainwater captured in rooftop media then evaporates or is transpired by plants back into the atmosphere. Rainwater in excess of the media capacity is detained in a drainage layer before flowing to roof drains and downspouts. Green roofs are highly effective at reducing or eliminating rooftop runoff from small to medium storm events, which can reduce downstream pollutant loads; however, green roofs do not typically improve the quality of captured rainwater. In addition to stormwater volume reduction, green roofs offer an array of benefits, including extended roof lifespan (due to additional sealing, liners, and insulation), improved building insulation and energy use, reduction of urban heat island effects, opportunities for recreation and rooftop gardening, noise attenuation, air quality improvement, bird and insect habitat, and aesthetics (Tolderlund 2010; Berndtsson 2010; Getter and Rowe 2006). Green roofs can be designed as extensive, shallow-media systems or intensive, deep-media systems depending on the design goals, roof structural capacity, and available funding. Extensive green roofs in the San Antonio region may require drip irrigation to sustain vegetation through hot summer months, but air conditioner condensate or harvested rainwater can be used for this purpose. To improve vegetation resistance and resilience, a biodiverse, locally-adapted plant palette should be used. Even with careful plant selection, many “green” roofs will remain brown during much of the year. *Blue roofs* are another form of rooftop runoff management also known as *rooftop ponding areas* or *rooftop detention* that can be effective for volume and flow control. Brown roofs are another form of rooftop runoff management focused on grasses or other “brown” vegetation rather than succulents, although this manual focuses on vegetated roofs because of their multi-use benefits. Additional information and design recommendations for blue roofs and brown roofs can be found in *Guidelines for the Design and Construction of Stormwater Management Systems* from the New York City Department of Environmental Protection and New York City Department of Buildings. Table 3-7 describes the advantages and limitations of green roofs.

Table 3-7. Advantages and limitations of green roofs

Advantages	Limitations
<ul style="list-style-type: none"> • Reduces stormwater volume and peak flow through evapotranspiration • Independent of site soils and geological setting • Can be used to reduce size of downstream BMPs • Improve building energy use and reduce energy costs • Enhance roof lifespan • Provide rooftop recreation and gardening opportunities • Reduce noise and air pollution • Provide urban bird and insect habitat • Improve aesthetics and increase property values (if visible) 	<ul style="list-style-type: none"> • Structural constraints could preclude use • Installation can be challenging in certain locations • Tend to be costly compared to other stormwater volume reduction practices • Although total stormwater volume is reduced, tend to export high nutrient concentrations and possibly pathogens (Berndtsson 2010) • Roof slopes steeper than 45° tend to require special design • May require irrigation for maintenance of vegetation during summer months (depends on plant selection and design goals)

3.4.2.1 Hydrologic Functions

The main benefits of green roofs are from significant rainfall volume retention, evapotranspiration, and reduced peak discharge from rooftops. While hydrologic performance of green roofs varies with media and material type, roof pitch, vegetation, climate, and season, green roofs tend to retain (on average) between 45 and 75 percent of annual rainfall (Berndtsson 2010). Vegetation has been shown to significantly enhance rooftop rainwater retention when compared with unplanted soil media, especially in the summer and in arid environments, although the majority of water retention and evaporation occurs in the soil media (Wolf and Lundholm 2008; Berndtsson 2010; Schroll et al. 2011). High runoff retention mimics evapotranspiration and canopy interception of natural systems, which shifts the urban water balance more toward predevelopment hydrology conditions.

3.4.2.2 Water Quality Performance

The body of knowledge surrounding green roof effluent quality is limited, but in general, green roofs are expected to export higher phosphorus and nitrogen concentrations than measured in rainfall (Berndtsson 2010). This is mainly from decomposition and release of nutrients from organic matter in the green roof soil media. Nevertheless, overall nutrient loads can be reduced when water volume reduction is considered (Kohler et al. 2002). Green roofs also tend to reduce heavy metal loads relative to incoming loads from precipitation (Berndtsson 2010).

3.4.2.3 Applications and Configurations

Appendix B.5 outlines major design components and site considerations and describes the process for designing green roofs. Green roofs are typically differentiated into two categories (intensive and extensive) based on desired function and structural capacity of the roof. Some examples of each type are provided below.

Extensive Green Roof

Green roofs with shallow, lightweight media are generally known as extensive. Media depths typically range from 4 to 6 inches to minimize loading on structures. Extensive green roofs are typically implemented solely for stormwater management, although alternative benefits are often realized (including reduced energy costs, improved roof lifespan, and pollinator habitat). An example of an extensive green roof is provided in Figure 3-15.



Figure 3-15. Extensive green roofs reduce stormwater runoff while providing cooling effects, Hipolito F. Garcia Federal Building and United States Courthouse, San Antonio, Texas. Source: Joss Growers

Intensive Green Roof

Roof gardens and rooftop parks with media deeper than 6 inches are commonly known as intensive green roofs. Unlike extensive green roofs, intensive green roofs are typically installed primarily for recreational and aesthetic purposes and provide stormwater benefits as an auxiliary function. Because deep media depth exerts high loads on underlying structures, implementation of intensive green roofs is common on the top level of parking decks, high-rise buildings, and other structures specifically designed for extreme loading. An example of an intensive green roof is shown in Figure 3-16.



Figure 3-16. Intensive green roofs provide recreational, aesthetic, and educational opportunities in addition to stormwater benefits, James Madison High School Agriscience Building, San Antonio, Texas. Source: Bender Wells Clark Design

3.4.3 Sand Filter

A sand filter is a treatment system used to remove particulates and solids from stormwater runoff by facilitating physical filtration. It is a flow-through system designed to improve water quality from impervious drainage areas by slowly filtering runoff through sedimentation and filtration chambers. With increased detention time, the sedimentation chamber allows larger particles to settle in the chamber. The filtration chamber removes pollutants and enhances water quality as the stormwater is strained through a layer of sand. The treated effluent is collected by underdrain piping and discharged to the existing stormwater collection system or another BMP. Advantages and limitations of sand filters are outlined below in Table 3-8.

Table 3-8. Advantages and limitations of sand filters

Advantages	Limitations
<ul style="list-style-type: none"> • Efficient removal of suspended solids, heavy metals, oil and grease, particle-bound nutrients, and pathogens • Can effectively reduce peak runoff rates for relatively frequent storms, reduce runoff volumes, and recharge ground water if soil conditions allow • Flexible to adapt to urban retrofits • Can incorporate deeper ponding depths and require less space • Can be placed underground in areas where space is limited • Can have high infiltration rates 	<ul style="list-style-type: none"> • Surface layer can clog over time (though it can be restored) • Frequent trash removal might be required, especially in high-traffic areas • Vigilance in protecting native soils from compaction during construction might be necessary (for infiltrating systems) • Can be unattractive in some areas • Standing water in sedimentation/grit chambers can provide vector breeding habitat • Higher overall cost for implementation

3.4.3.1 Hydrologic Functions

Sand filters are filtering BMPs that remove trash and pollutants by passing stormwater vertically through a sand media. Sand filters are generally applied to land uses with a large fraction of impervious surfaces and ultra-urban locations. Although an individual sand filter can handle only a small contributing drainage area, multiple units can be dispersed throughout a large site. Two strategies are available for incorporating sand filters into the site design. One option is the open basin or above ground design that allows sunlight penetration to enhance pathogen removal. The second option is a closed basin or below ground design that requires very little space in a site but has reduced pollutant-removal capabilities. Because sand filters can be implemented underground, they can also be used in areas with limited surface space.

Sand filters are designed primarily for water quality enhancement; however, surface sand filters can store a substantial volume of water and be used for peak flow attenuation. Sand filters typically employ underdrain systems to collect and discharge treated stormwater but can also be designed as infiltration-type systems when in soils with sufficient permeability or infiltration rates. Infiltration further enhances a sand filter’s ability to mitigate flood flows and reduces the erosive potential of urban runoff.

3.4.3.2 Water Quality Performance

Sand filters are capable of removing a wide variety of pollutant concentrations in stormwater via settling, filtering, and adsorption processes. Sand filters have been a proven technology for drinking water treatment for many years and are capable of removing many particulate-bound urban stormwater pollutants including TSS, particulate-bound nutrients, and metals (Barrett 2008). Sand filters are volume-based BMPs intended primarily for treating the water quality design volume. In many cases, sand filters are contained within enclosed concrete or block structures with underdrains; therefore, only minimal volume reduction occurs via evaporation as stormwater percolates through the filter to the underdrain.

Because sand filters rely on filtration as the primary function for pollutant reduction, infiltration rates could be higher than what is recommended for a bioretention area, allowing a greater volume to pass through the media in a short time. That requires less surface area of the BMP to treat the same volume with a lower performance for some pollutants. Sand filters generally have high

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removal rates for sediment, BOD, and fecal coliform bacteria (USEPA 1999). Effluent concentrations of sediment and sediment-bound pollutants tend to be relatively independent of influent concentrations, indicating sand filters can be expected to discharge constant effluent quality regardless of influent concentrations (Barrett 2008). TSS removal rates range from 74 to 95 percent, with a typical efficiency of 90 percent (Bell et al. 1995; Horner and Horner 1995; Barrett 2003, 2008, 2010). TSS effluent concentrations ranged from 13 to 25 mg/L for five study sites in Texas (compared to influent concentrations of 69 to 304 mg/L; Barrett 2010).

Barrett (2010) reported the following pollutant removal rates (percent reductions in event mean concentration from inlet to outlet) for five sand filter study sites in Texas:

- Total phosphorus: –14 percent (export) to 69 percent (reduction)
- BOD: –27 percent (export) to 55 percent (reduction)
- Zinc: 35 to 87 percent reduction
- Copper: 14 to 59 percent reduction
- Lead: 61 to 86 percent reduction
- Fecal coliform: –70 percent (export) to 54 percent (reduction)
- Fecal streptococcus: 11 to 68 percent reduction

In another study, Barrett (2008) reported that total nitrogen is modestly removed, with an average efficiency of approximately 20 percent, while removal of total metals ranges from 50 to 87 percent, with lower removal of dissolved metals.

3.4.3.3 Applications and Configurations

Appendix B.6 outlines major design components and site considerations and describes the process for designing sand filters. Typical site applications and configurations are described below.

Surface

Surface sand filters require some method of pretreatment, such as a filter strip or swale, to remove large solids and reduce the velocity of stormwater entering the BMP. Surface sand filters can be integrated into the site plan as recreational facilities such as volleyball courts or open space as shown in Figure 3-17.



Figure3-17. Surface sand filter, Parman Library, San Antonio, Texas. Source: Bender Wells Clark Design

Subsurface

Subsurface sand filters require very little space and are easily incorporated below ground into the edge of parking lots and roadways. Subsurface sand filters require a pretreatment sedimentation chamber that is a minimum of 1.5 feet wide to allow for settling of large solids. An example of a subsurface sand filter with a sedimentation chamber is shown in Figure 3-18.



Figure 3-18. Subsurface sand filter, Raleigh, North Carolina. Source: Tetra Tech

3.5 Volume-Storage and Reuse BMPs

Stormwater wetlands can be effectively implemented in open space areas to temporarily capture and store runoff where infiltration is limited or not feasible. Using BMPs around buildings is intended to maximize rainfall interception and minimize pollutant introduction into stormwater. Cisterns and rain barrels are examples of volume-storage and reuse BMPs that reduce runoff washed from buildings. With the goal of reducing the total runoff volume washed into the traditional stormwater conveyance system (MS4), stormwater wetlands, cisterns, and rain barrels are especially effective in capturing volumes from smaller storm events. Once captured, the stormwater is slowly released between storm events and can be used for irrigation. The controlled release from cisterns reduces peak storm volumes and, therefore, reduces runoff and erosion potential.

3.5.1 Stormwater Wetlands

Stormwater wetlands are engineered, shallow-water ecosystems designed to treat stormwater runoff. Commonly implemented in low-lying areas, stormwater wetlands are well suited to areas along river corridors where water tables are higher. Sediment and nutrients are efficiently reduced by stormwater wetlands by means of sedimentation, chemical and biological conversions, and uptake. Stormwater wetlands provide flood control benefits by storing water and slowly releasing it over 2 to 5 days. In addition to stormwater management, stormwater wetlands provide excellent plant and wildlife habitat and can often be designed as public amenities. Research has indicated that a home located next to stormwater wetlands can have a 20 to 30 percent higher selling price (Russell et al. 2012). Advantages and limitations of stormwater wetlands are outlined in Table 3-9.

Table 3-9. Advantages and limitations of stormwater wetlands

Advantages	Limitations
<ul style="list-style-type: none"> • Excellent sediment and nutrient reduction • Useful in low-lying areas, areas with high water tables, or where infiltration is otherwise restricted/discouraged • Construction and design techniques similar to conventional detention ponds • Provide multi-benefit uses by enhancing biodiversity and providing recreational/educational opportunities • Typically require fewer vector control efforts than unvegetated ponds because properly maintained habitat supports mosquito predators (dragonflies and fish) 	<ul style="list-style-type: none"> • Limited use in semi-arid climates where supplemental water would be required to maintain water level (a site-specific water balance must be performed to justify implementation)

3.5.1.1 Hydrologic Functions

Runoff enters stormwater wetlands and is stilled in a forebay where large solids and debris are captured. The design volume then fills the wetland to a depth of 12 inches or less and drains over 2 to 5 days through a drawdown orifice installed at the elevation of the permanent pool. Runoff in excess of the design volume can bypass to the downstream stormwater network or can be detained using a riser structure or weir. Although stormwater wetlands can mitigate peak discharge, they are

not designed for volume reduction—in fact, infiltration is discouraged to ensure that permanent pools are maintained for plant survival and aesthetic purposes (more information in Appendix B.7).

3.5.1.2 Water Quality Performance

Similar to natural wetlands, water quality improvement is effectively achieved in constructed wetlands through physicochemical and biological processes as water is temporarily stored. Specific unit processes include sedimentation, denitrification, and uptake. Consequently, the flow path through the wetland should be maximized to increase residence time and contact with vegetation, soil, and microbes. Very high sediment removal efficiencies have been reported for properly sized stormwater wetlands (50 to 80 percent reduction), with average effluent concentrations near 9 mg/L (Hathaway and Hunt 2010; Geosyntec Consultants, Inc. and Wright Water Engineers, Inc. 2012). Subsequently, particle-bound metals are thought to be reduced as sediment falls out of suspension, and significant reduction of total copper, total cadmium, total lead, and total zinc is expected (although metals can dissociate from sediment and organic matter into solution under anaerobic conditions; Newman and Pietro 2001; Geosyntec Consultants, Inc. and Wright Water Engineers, Inc. 2012).

High phosphorus removal rates have been observed in stormwater wetlands, but, similar to metals, phosphorus can desorb from sediments under anaerobic conditions (Hathaway and Hunt 2010). Stormwater wetlands typically perform well for nitrate removal because the anaerobic conditions and organic material in wetland sediment create an ideal environment for denitrification (converting nitrate into nitrogen gas). Significant nitrate reduction is commonly observed in stormwater wetlands, but total nitrogen reduction depends on the species and concentration of incoming nitrogen (Hathaway and Hunt 2010; Moore et al. 2011; Geosyntec Consultants, Inc. and Wright Water Engineers, Inc. 2012). Pathogen removal in stormwater wetlands is expected because of predation, solar radiation, and sedimentation (Davies and Bavor 2000; Struck et al. 2008; Geosyntec Consultants, Inc. and Wright Water Engineers, Inc. 2012); furthermore, wetlands tend to reduce bacteria more than do traditional wet detention ponds (Davies and Bavor 2000).

3.5.1.3 Applications and Configurations

Appendix B.7 outlines major design components and site considerations and describes the process for designing stormwater wetlands. In general, stormwater wetlands are particularly well suited to low-lying sites with large drainage areas. The configuration of the stormwater wetland will vary by site and can be adapted to the available space and desired functions. Long, linear wetlands can be installed along the perimeter of sites, smaller pocket wetlands can be distributed throughout a development, or larger wetlands can be installed at the downstream end of a catchment. Figure 3-19 and Figure 3-20 illustrate examples of stormwater wetlands.



Figure 3-19. Large linear stormwater wetland, Lenoir, North Carolina. Source: Tetra Tech



Figure 3-20. Small stormwater wetlands along the perimeter of a neighborhood, Wilmington, North Carolina. Source: Tetra Tech

3.5.2 Stormwater Cisterns

Cisterns or their smaller counterpart, rain barrels, are containers that capture runoff and store it for future use. With control of the timing and volume, the captured stormwater can be more effectively released for irrigation or alternative grey water uses between storm events. Rain barrels tend to be smaller systems, less than 100 gallons. Cisterns are larger systems that can be self-contained aboveground or belowground and generally larger than 100 gallons. Belowground systems often require a pump for water removal. For San Antonio and surrounding areas, cisterns and rain barrels primarily provide control of stormwater volume; however, water quality improvements can be achieved when cisterns and rain barrels are used in a treatment train with BMPs such as bioretention areas. Water in cisterns or rain barrels can be controlled by permanently open outlets or operable valves depending on project specifications. Cisterns and rain barrels can be a useful method of reducing stormwater runoff volumes in urban areas where site constraints limit the use of other BMPs. Advantages and limitations of rainwater harvesting are outlined in Table 3-10.

Table 3-10. Advantages and limitations of stormwater cisterns

Advantages	Limitations
<ul style="list-style-type: none"> • Provides peak flow mitigation for frequent and infrequent storm events • Aids in infiltration by delaying runoff • Variable configurations to meet site constraints • Can reduce the size of infiltration BMPs • Can be designed for high visibility to raise stormwater awareness or can be hidden from view • Effective where underground utilities or other constraints preclude use of surface/subsurface storage BMPs • Can be designed to supplement or replace nonpotable water supplies (for nonresidential uses) or for irrigation (residential or nonresidential) • Rainwater harvesting equipment is exempt from sales tax under Texas Tax Code 151.355 	<ul style="list-style-type: none"> • Requires regular maintenance of inlet filters and mosquito control screens • Can require structural support • Reuse systems may require filtration and disinfection per intended use and local plumbing codes

3.5.2.1 Hydrologic Functions

Cisterns are typically placed near roof downspouts such that flows from existing downspouts can be easily diverted into the cistern. Runoff enters the cistern near the top and is filtered to remove large sediment and debris. Collected water exits the cistern from the bottom or can be pumped to areas more conducive for infiltration. Cisterns can be used as a reservoir for temporary storage or as a flow-through system for peak flow control. Cisterns are fitted with a valve that can hold the stormwater for reuse, or they release the stormwater from the cistern at a rate below the design storm rate. Regardless of the intent of the storage, an overflow must be provided if the capacity of the cistern is exceeded. The overflow system should route the runoff to a BMP for treatment or safely pass the flow into the stormwater drainage system. The overflow should be conveyed away from structures. The volume of the cistern should be allowed to slowly release, preferably into a BMP for treatment or into a landscaped area where infiltration has been enhanced.

Cisterns have been used for millennia to capture and store water. Droughts in recent years have prompted a resurgence of rainwater harvesting technology as a means of offsetting potable water use. Studies have shown that adequately designed and used systems reduce the demand for potable

water and can provide important hydrologic benefits (Vialle et al. 2012; DeBusk et al. 2012). Hydrologic performance of rainwater harvesting practices varies with design and use; systems must be drained between rain events to reduce the frequency of overflow (Jones and Hunt 2010). When a passive drawdown system is included (e.g., an orifice that slowly bleeds water from the cistern into an adjacent vegetation bed or infiltrating practice), significant runoff and peak flow reduction can be achieved (DeBusk et al. 2012; AECOM Technical Service, Inc. 2011).

3.5.2.2 Water Quality Performance

Because most rainwater capture systems collect rooftop runoff, the water quality of runoff captured in cisterns is largely determined by surrounding environmental conditions (overhanging vegetation, bird and wildlife activity, atmospheric deposition, and such), roof material, and cistern material (Thomas and Greene 1993; Despins et al. 2009; Lee et al. 2012). Rooftop runoff tends to be relatively clean regarding physical and chemical pollutants, but elevated microbial counts are typical (Thomas and Greene 1993; Lye 2009; Gikas and Tsihrintzis 2012; Lee et al. 2012). Physicochemical contaminants can be further reduced by implementing a first-flush diverter (discussed later); however, first-flush diverters can have little impact on reducing microbial counts (Lee et al. 2012; Gikas and Tsihrintzis 2012).

The pollutant reduction mechanisms of cisterns are not yet well understood, but it is thought that water quality improvement can be achieved by sedimentation and biochemical transformations (given adequate residence time). Despite limited data describing reduction in stormwater contaminant concentrations in cisterns, rainwater capture can greatly reduce pollutant loads to waterways if stored rainwater is infiltrated into surrounding soils using a low-flow drawdown configuration or when it is used for alternative purposes such as toilet flushing or vehicle washing (Khastagir and Jayasuriya 2010). Rainwater capture systems can also be equipped with filters to further improve water quality.



Figure 3-21. Typical plastic cistern, Pine Knoll Shores, North Carolina. Source Tetra Tech

3.5.2.3 Applications and Configurations

Appendix B.8 outlines major design components and site considerations and describes the process for designing rainwater capture systems that are in compliance with the San Antonio plumbing code (City of San Antonio 2009). Additional Texas-specific resources are provided in TCEQ (2011), Texas Water Development Board (2005), and Texas A&M AgriLife Extension Services (2013). Typical site applications and configurations are described below.

A cistern typically holds several hundred to several thousand gallons of rainwater that can be used in a variety of settings in residential, commercial, governmental, and industrial applications. Cisterns provide non-potable water for irrigation, toilet flushing, cooling system makeup, and equipment and vehicle washing and come in a variety of shapes, colors, and configurations. Figure 3-21 shows a typical above ground plastic cistern and Figure 3-22 shows the same cistern with a

wooden wrap. Cisterns can also be decorative such as the one shown in Figure 3-23, or below ground as shown in Figure 3-24.



Figure 3-22. Wood wrapped cisterns, Pine Knoll Shores, North Carolina. Source: Tetra Tech



Figure 3-23. Decorative cisterns, Robert B. Green Campus, University Health System, San Antonio, Texas.



Figure 3-24. Large below ground cistern under construction, Confluence Park, San Antonio, Texas. Source: San Antonio River Foundation

Smaller cisterns (less than 100 gallons), commonly referred to as rain barrels, are mostly used on a residential scale (Figure 3-25). Rain barrels are much less complicated to install because of their size, yet they have similar components as cisterns. Rain barrels require an inlet connection to the downspout, an outlet, and an overflow. Water that is collected can be used to supplement municipal water for nonpotable uses, primarily irrigation. Although useful for raising public awareness and for meeting basic irrigation needs, rain barrels do not typically provide substantial hydrologic benefits because they tend to be undersized relative to their contributing drainage area. Nevertheless, modeling has suggested that the cumulative effects of watershed-wide rain barrel implementation in the San Antonio region (particularly when paired with rain gardens) can have significant impacts on 100-yr peak flow and annual volume reduction (AECOM Technical Services, Inc. 2011). Figure 3-26 shows rain barrels adequately sized for the contributing roof area.



Figure 3-25. Residential rain barrel.



Figure 3-26. Rain barrels adequately sized for contributing roof area, Asheville, North Carolina. Source: Tetra Tech

3.5.3 Extended Detention Basins

Extended Detention (dry) Basins (EDBs) are detention or sedimentation basins that discharge the design water quality volume of stormwater runoff over an extended period, usually from 24 to 48 hours. These devices function similar to flood control / detention basins, but include the extended holding period to encourage settling of sediment and particulate matter, exposure to UV sunlight, and other processes that treat pollutants before discharge. Therefore, in addition to a limited water quality benefit, EDBs provide the additional benefit of mitigating flooding by reducing peak discharge of storm water runoff and providing additional flood detention storage. In addition, controlling runoff rates helps to protect the downstream receiving waters from erosion. Ideally, an extended detention basin is designed as part of a treatment train with other BMPs such as bioretention.

EDBs include a variety of designs and may include several components to improve performance including sediment forebays, separate ponding areas, trickle channels, and trash racks. EDBs are commonly categorized under single and double stage variations. Single-stage EDBs do not have large designed permanent pools. These devices promote removal of sediment, sediment associated constituents, and buoyant material removal. Two-stage EDBs incorporate small wetland marshes, ponding areas, or micropools at the downstream section of the basin to promote biological uptake. To comply with this manual, EDBs must include the two-stage design. These additional elements promote soluble pollutant removal (Barrett, 2005). EDBs can be retrofitted from flood control detention basins and roadway stormwater outfalls. EDBs are most often used in residential neighborhoods, commercial areas, and industrial sites, but can also be used for roads and parking lots.

EDBs work best for watersheds larger than 5 acres. The minimum size of drainage area to EDBs is limited by the orifice design that may be prone to clogging for small watersheds. For the EDB device to function properly, the project area must also have sufficient area to hold the design water quality volume and hydraulic head. Advantages and limitations of extended detention basins are outlined in Table 3-11.

Table 3-11. Advantages and limitations of extended detention basins

Advantages	Limitations
<ul style="list-style-type: none"> • Ease of construction, operation, and maintenance • Multipurpose facility, such as pollinator habitat passive recreation, open space and flood control • Control of channel erosion and enlargement caused by change to flow behavior 	<ul style="list-style-type: none"> • Maintenance requirements to address sediment and debris accumulations • Not recommended for sites with less than 2 impervious acres and watersheds less than 5 acres • Concern that undesirable appearance can detract from home values

3.5.3.1 Hydrologic Functions

As discussed previously, impervious areas increase the total peak discharge and change the timing of the peak discharge. Extended detention facilities can mitigate the hydrologic impacts of upstream impervious areas by discharging the designed volumes over a longer period and decreasing the rates of discharge and delaying the peak discharge. Studies have also suggested that grass lined detention basins provide “substantial volume reduction, especially in smaller events” (International

BMP Database, 2011). Through these hydrologic functions, EDBs can mitigate potential negative impacts including destabilization, erosion, and impacts due to sediment transport variation on receiving waters.

The hydrologic functionality of the EDB is linked to the design of the system, soil characteristics, and storm characteristics. The rate of release is established by the outlet control structure of the EDB, usually an orifice structure designed at a specific size to control the discharge from the basin. These basins must also include an overflow outlet to control the discharge rate and location of discharge of larger volumes that exceed the storage volume of the EDB. Trickle channels also prevent shallow ponding in front of the structure, eliminating creation of a breeding ground for mosquitoes (UDFCD, 2015).

Extended detention basins can be used with almost all soils and geology; however, minor design adjustments may be required to account for regions with rapidly percolating soils such as sand. In areas where there are water quality hot spots as defined in this manual, EDBs may need an impermeable liner to prevent infiltration and groundwater contamination. The base of the extended detention facility should not intersect the water table. A permanently wet bottom may become a mosquito breeding ground. Research in Southwest Florida (Santana et al., 1994) demonstrated that intermittently flooded systems, such as dry extended detention ponds, produce more mosquitoes than other pond systems, particularly when the facilities remained wet for more than 3 days following heavy rainfall. Systems with a large permanently wet feature are considered stormwater wetlands and should be designed accordingly.

The incorporation of grassy swales or vegetative strips upstream or downstream of the device allows additional mitigation of hydrologic impacts. Pre-treatment by swales upstream of the basin can extend the function life and increase removal capacity by reducing incoming velocities and capturing coarse sediment.

3.5.3.2 Water Quality Performance

The performance of the EDB system relies on the design and maintenance of the EDB. With a primary pollutant removal pathway of settling, EDBs are most effective for removal of sediment and particle-associated pollutants. The effectiveness of the EDB is enhanced by designing with the appropriate dimensions, including a long flow path to prevent short circuiting, structures to reduce velocities, and avoiding stagnant pools. The incorporation of a permanent micropool into the design can provide improved performance for soluble pollutants and sediment-associated pollutants such as nutrients by preventing resuspension and flushing of sediment from the basin (CASQA, 2003; International BMP Database, 2011; UDFCD, 2015). A small permanent pool will be required to meet the definition of an EDB. Sediment forebays are designed to prevent scour and remove sediment. Forebays can serve as pre-treatment and help to reduce sediment load before discharge into the primary basin and reduce sediment accumulation and potentially resuspension within the primary basin. Studies have shown moderate reductions for particle associated pollutants.

If infiltration is appropriate for the site, the volume reduction and associated pollutant load reduction will improve the water quality benefit to downstream waters. Infiltration is especially important for the effectiveness of EDBs for pollutants that have high solubility and are not likely to settle out. Accumulated sediments need to be cleaned out as often as necessary to prevent potential re-suspension and discharge. Although studies show effective removal of sediment associated pollutants, these devices are less effective at removing dissolved pollutants. Some

enhanced designs maximize nutrient removal and runoff reduction (Chesapeake). Studies have shown that EDBs can provide some benefit for removal of bacterial indicators, TSS, total lead, total zinc, particulate copper, particulate lead, and particulate zinc. Unlined extended basins are preferred except where potential groundwater contamination is an over-riding concern (CASQA, 2003). The performance of EDBs can also be enhanced by incorporating a treatment train approach, and using grassy swales or vegetative strips upstream or downstream of the device for additional treatment. Vegetated BMPs have been shown to provide greater pollution removal than concrete basins (De J. Quinonez-Diaz et al. 2001; Garcia and Becares 1997; Gersberg et al. 1986). Export of sediment is not as common for vegetated earthen basins, where the vegetation helps to stabilize the retained sediment. In addition, vegetation can act to trap contaminants, reduce velocities, and increase rates of evapotranspiration and uptake (Bledsoe 2001; CASQA, 2003).

3.5.3.3 Applications and Configurations

Appendix B.8 describes major design components and site considerations and then outlines the process for designing EDBs. The effectiveness of the EDB depends on numerous design components, including distance between inlet and outlet, depth of the basin, length to width ratio, pre-treatment (upstream strips or swales or a sediment forebay), outlet design structure, and the presence or absence of a permanent pool (Villarreal, 2006). EDBs should be integrated into treatment trains for appropriate levels of water quality treatment. EDBs are particularly well suited to act as the last portion of the treatment train. To provide treatment of the maximum potential drainage area, they should be located at the downstream end of a catchment. The configuration of the EDB will vary by site and can be adapted to the available space and desired functions. Figure 3-27 identifies the various components of an EDB, and Figure 3-28 provides before and after photos of a detention basin that was retrofitted to function as an EDB.

3.5.3.4 Retrofitting Detention Basins to Extended Detention Basins

It may be possible to convert existing detention basins to extended detention basins in order to increase the water quality benefits of the existing storm water facility. Determining whether or not this is feasible will depend on the size of the drainage area, the space available, underlying geologic conditions, and local regulations. The best retrofit sites are in areas that have available space (i.e. not highly urbanized), have sufficient storage capacity, and have large enough drainage area to contribute meaningfully to catchment water quality (EPA, 2011).

The most limiting obstacle in determining whether or not a dry basin can be upgraded to an extended detention basin is available storage volume. Some basins are oversized when they are first constructed and may not need much in the way of increased volume. For other basins, strategies two through five can be considered as methods for adding water quality storage capacity.

- (1) If the pond is oversized for quantity control, convert this storage into water quality treatment storage.
- (2) If underlying geologic conditions allow (i.e. no bedrock or high water table), excavate the pond bottom to remove sediment build up and increase storage capacity.
- (3) Raise the height of the embankment surrounding the basin to increase storage capacity. All emergency spillways and dams must pass safety inspections.

(4) Modify the riser to create a multi-stage structure that will slowly draw down the water quality volume, while still discharging larger volumes at the flood control rate.

(5) Modify the internal design of the basin by increasing flow paths, adding wetland elements, or installing a forebay.

(From Schueler, 2007).



Figure 3-27. Extended Detention Basin, Grant Ranch, Colorado. Source: Urban Drainage Flood Control District



Figure 3-28. Pond retrofit before and after. Source: Crosspointe and Fairfax County, VA

Operators of existing flood control and detention basins should consider retrofitting existing facilities to function as extended detention basins. By consulting watershed assessments, areas can be identified with poor habitat and water quality that need to be improved. The best retrofit sites are areas located adjacent to existing channels, are in existing open areas, have sufficient runoff storage capacity, can divert runoff to a potential treatment area, and have a sufficient drainage area to contribute meaningfully to catchment water quality (EPA, 2011). Five strategies can be used to retrofit storage into an existing pond, including (1) excavate the pond bottom, (2) raise the embankment, (3) modify the riser, (4) trade existing flood control storage capacity, (5) fix internal design geometry and/or add forebay (Schueler, 2007).

3.6 Conveyance and Pretreatment BMPs

3.6.1 Vegetated Swales

Vegetated swales are shallow, open grass channels that are LID alternatives to traditional curbs and gutters. Swales are designed to convey runoff while providing limited pollutant removal by sedimentation and horizontal filtration through vegetation. Swales are effective for pretreatment of concentrated flows before discharge to a downstream BMP. **Vegetated swales should not be confused with bioswales, which rely on vertical filtration of runoff through subsurface bioretention media.** Compared with other LID practices, vegetated swales have a relatively low construction cost, a moderate maintenance burden, and require only a moderate amount of surface area.

Advantages and limitations of vegetated swales are outlined in Table 3-12.

Table 3-12. Advantages and limitations of vegetated swales

Advantages	Limitations
<ul style="list-style-type: none"> • Combines limited stormwater treatment with runoff conveyance • Often less expensive than curb and gutter • Provides limited peak flow reduction • Can be installed in narrow, marginal spaces along roadways and parking lots to convey runoff to downstream BMPs 	<ul style="list-style-type: none"> • Higher maintenance than curb and gutter • Impractical in areas with very flat grades or steep topography (can cause nuisance standing water and vector issues) • Not as effective for high flow volumes/velocities • Not effective for volume reduction

3.6.1.1 Hydrologic Functions

Vegetated swales are flow-based BMPs intended primarily for water quality treatment. Depending on site slope and soil conditions, swales provide minimal volume reduction. Vegetated swales are not intended to be a primary BMP for meeting stormwater volume and quality goals, although they can help reduce the peak flow rate by increasing the site's T_C and providing marginal volume reduction through infiltration.

3.6.1.2 Water Quality Performance

Vegetated swales can remove sediment and particulate-bound pollutants by sedimentation and filtration (Deletic and Fletcher 2006). Particle removal performance primarily depends on flow-rate, particle setting velocity, and flow length (Deletic and Fletcher 2006; Yu et al. 2001; Bäckström 2003; Bäckström 2006). In some cases, swales can export metals and pathogens (Bäckström 2003; USEPA 2012). The effectiveness of vegetated swales can be enhanced by adding check dams at approximately 50-foot increments along their length (depending on slope). The dams maximize the retention time in the swale, decrease flow velocities, and promote particulate settling. Incorporating vegetated filter strips parallel to the top of the channel banks can help to treat sheet flows entering the swale (Barrett et al. 1998).

3.6.1.3 Applications and Configurations

Appendix B.9 outlines major design components and site considerations and describes the process for designing vegetated swales. Although it might be difficult to use vegetated swales to receive stormwater runoff in urban areas because of space constraints, they can be used to receive stormwater on a wide variety of development sites in rural and suburban areas, including residential, commercial, industrial, and institutional development sites. Figure 3-29 shows a vegetated swale at James Madison High School Agriscience Building in San Antonio. Vegetated swales also are well suited for use in the right-of-way of linear transportation corridors; Figure 3-30 shows a vegetated swale along a roadside.



Figure 3-29. Vegetated swale in an institutional setting, James Madison High School Agriscience Building, San Antonio, Texas. Source: Bender Wells Clark Design



Figure 3-30. Roadside vegetated swale, San Antonio, Texas. Source: Tetra Tech

3.6.2 Vegetated Filter Strips

Vegetated filter strips are bands of dense, permanent vegetation with a uniform slope, designed to provide pretreatment of runoff generated from impervious areas before flowing into another BMP as part of a treatment train. Vegetated filter strips on highly permeable soils can also provide infiltration, improving volume reduction. Increased infiltration can decrease the necessary horizontal length. Such characteristics make it ideal to use vegetated filter strips as a BMP around roadside shoulders or safety zones.

Vegetated filter strips are implemented for improving stormwater quality and reducing runoff flow velocity. As water sheet flows across the vegetated filter strip, the vegetation filters out and settles the particulates and constituents, especially in the initial flow of stormwater. Removal efficiency often depends on the slope, length, gradient, and biophysical condition of the vegetation in the system.

Advantages and limitations of filter strips are outlined in Table 3-13.

Table 3-13. Advantages and limitations of filter strips

Advantages	Limitations
<ul style="list-style-type: none"> • Good pretreatment BMP • Simple to install (often requiring only minimal earthwork and planting) • Simple, aesthetically pleasing landscaping • Low cost/maintenance 	<ul style="list-style-type: none"> • Must be sited next to impervious surfaces • Might not be suitable for industrial sites or large drainage areas • May require large footprint for sufficient treatment • Requires sheet flow across vegetated area • Application in arid areas is limited because of the need for thick vegetation • Does not provide attenuation of peak flows

3.6.2.1 Hydrologic Functions

Filter strips are often used as pretreatment devices for other, larger-capacity BMPs such as bioretention areas and assist by filtering sediment and associated pollutants before they enter the larger-capacity BMP, preventing clogging and reducing the maintenance requirements for larger-capacity BMPs. Filter strips provide an attractive and inexpensive vegetative BMP that can be easily incorporated into the landscape design of a site. Filter strips are commonly used in the landscape designs of residential, commercial, industrial, institutional, and roadway applications. They must be adjacent to the impervious areas they are intended to treat. Vegetated filter strips are flow-based BMPs intended for achieving water quality treatment. Depending on site slope and soil conditions, they can provide some volume reduction and can increase a site’s time of concentration (T_c). However, vegetated filter strips are not intended to act as a standalone, primary BMP for meeting volume-reduction objectives.

3.6.2.2 Water Quality Performance

Vegetated filter strips are well suited for treating runoff from roads, highways, driveways, roof downspouts, small parking lots, and other impervious surfaces. They can also be used along streams or open vegetated waterways to treat runoff from adjacent riparian areas. In such applications, they are commonly referred to as buffer strips. Because of their limited ability to provide peak attenuation and their ability to decrease sediment loads, vegetated filter strips are often used as a pretreatment for other BMPs such as bioretention or permeable pavement. They have not been widely accepted as primary BMPs because of the wide range of pollutant removal efficiencies (Schueler et al. 1992; Young et al. 1996).

Whereas some assimilation of dissolved constituents can occur, filter strips are generally more effective in trapping sediment and particulate-bound metals and nutrients (in the absence of erosion; Knight et al. 2013; Winston et al. 2011). Nutrients that bind to sediment include phosphorus and ammonium; soluble nutrients include nitrate. Biological and chemical processes could help break down pesticides, uptake metals, and use nutrients that are trapped in the filter. Vegetated filter strips also exhibit good removal of litter and other debris when the water depth flowing across the strip is below the vegetation height.

3.6.2.3 Applications and Configurations

Appendix B.10 outlines major design components and site considerations and describes the process for designing filter strips. Figure 3-31 and Figure 3-32 show vegetated filter strips between impervious areas and bioretention facilities. Figure 3-33 shows a filter strip next to a parking lot.



Figure 3-31. Vegetated filter strip that pretreats roadway runoff, Apex, North Carolina. Source: Tetra Tech



Figure 3-32. Vegetated filter strip surrounding a bioretention area in a parking lot, Raleigh, North Carolina. Source: Tetra Tech



Figure 3-33. Vegetated filter strip next to a parking lot, San Antonio, Texas. Source: Tetra Tech

3.7 BMP Selection Matrix

Table 16 is a tool to help select practices according to site characteristics and constraints when considering LID stormwater management practices. Existing or expected site characteristics can be used to determine individual practices or a suite of practices that might be appropriate in site design. Vegetated swales and filter strips are not included in the table because this manual considers these practices appropriate for pretreatment and not as standalone water quality BMPs. In addition, relative cost considerations can assist in specific BMP selection, particularly between two or more BMPs that achieve the project's goal. As such, the table lists dollar signs as qualitative costs for a relative comparison between types of BMPs rather than actual values. BMP costs can vary widely and overlap between BMP types depending on the complexity of the BMP configuration required. Costs should be used as a relative guide with emphasis on the water quality performance and the site conditions and configuration in selecting the BMP type.

Estimated costs in this table and in Appendix B cover all components of construction and operation and maintenance for various-sized projects but do not cover other conveyance needs that might be applicable. Cost estimates are based on the design standards recommended in Appendix B and can vary widely by the necessary configuration of the BMP and site constraints. These cost numbers are estimates and intended for planning purposes only. The project manager must refine these numbers throughout the phases of design to prepare a more accurate project construction estimate for bidding purposes. Cost estimates, particularly the maintenance costs, do not account for cost savings accompanied with integrated practices, such as incorporating BMP retrofits into CIP projects or integrating bioretention areas into landscaping where the routine maintenance could be included in the budget for typical landscape maintenance. The inclusion of various sizes of projects in the maintenance costs attempts to include those costs in which an economy of scale has been observed. The sizes selected for this analysis were as follows:

- Large BMP system = 4,000 ft²
- Medium BMP system = 2,000 ft²
- Small BMP system = 500 ft²

These categories are based on typically sized BMPs and are intended to account for the varying degrees of economy of scale. Cost estimates for small BMPs could be used for the projects where the only maintenance required for the project will be for the BMPs. Estimates for the large systems could be used for projects where maintenance for landscaping as well as the BMPs will be accounted for providing an economy of scale. Fixed costs for maintenance, such as equipment, mobilization, and disposal, can be dispersed more effectively for larger more complex projects resulting in a lower unit cost. As a BMP area represents a system, the area can include the application of multiple BMPs. Appendix G also provides more detailed information on costs, including actual cost numbers, that are based on the frequency and type of maintenance required, such as routine maintenance (costs associated with maintenance required monthly up to every 2 years), intermediate maintenance (costs associated with maintenance required every 6 to 10 years) and replacement maintenance (costs associated with replacement of the system; estimated as a service life of 20 years). Table 3-14 does not include the more detailed frequency costs.

Once individual or groups of BMPs have been selected using this matrix, consult Appendix B to develop detailed designs and Appendix G to develop a more detailed cost estimate.

Table 3-14. LID management practice selection matrix according to site characteristics

Attribute	Bioretention		Bioswale		Permeable Pavement		Planter Boxes	Green Roofs	Sand Filter		Rainwater Capture	Stormwater Wetlands	Extended Detention Basin	
	Infiltrating	Lined	Infiltrating	Lined	Infiltrating	Lined			Infiltrating	Lined				
Edwards Aquifer Zone Allowed (see Section 2.2)	Artesian	All	Artesian	Artesian	Artesian, Contributing	All	All	All	Artesian	All	All	All	All (consider liner based on soils)	
Typical contributing drainage area (acres)	< 5		< 2		0 ^a		< 0.35	Rooftop	< 5		Rooftop	> 5	> 5	
Min. elevation difference between inlet and outlet (ft)	3.5 (2.5 if using IWS)		3.5 (2.5 if using IWS)		1 to 2 (depends on design)		2.5	N/A	2.5 (2 if using IWS)		N/A	2	2	
Separation of subgrade from bedrock and seasonal high water table (ft)	≥ 3		≥ 3		≥ 3		Above water table	N/A	≥ 3		Above water table and bedrock ^b	At or below permanent pool elevation	≥ 3	
Practice slope	< 2%		< 2%		< 2%		N/A	N/A	< 6%	< 6%	< 5%	< 5%		
Underdrain required?	If soil infiltration < 0.5 in/hr	Yes	If soil infiltration < 0.5 in/hr	Yes	If soil infiltration < 0.5 in/hr	Yes	Yes	N/A	If soil infiltration < 0.5 in/hr	Yes	N/A	N/A	N/A	
Pollutant Removal ^e	Sediments	High		High		High		High	Typically water quality is not improved by green roofs (although stormwater volume reduction can reduce total pollutant loads)	High		Pollutant removal provided by downstream BMP, refer to specific BMP for removal efficiency	High	Medium
	Nutrients	Medium		Medium		Low		Medium		Low			High	Medium
	Trash	High		High		High		High		High			High	High
	Metals	High		High		High		High		Low			High	Low
	Bacteria	High		High		Medium		High		Medium			High	Medium
	Oil and grease	High		High		Medium		High		Medium			High	Low
	Organics	High		High		Low		High		Medium			High	Medium
Runoff volume reduction	High	Low	High	Low	High	Low	Low	High	Low	Low	Varies based on cistern size and water demand	None	Medium	
Peak flow control	Medium		Medium		Medium		Low	Medium	Medium	Medium		High	High	
Setbacks (ft)	Structures	> 10		> 10		> 10		N/A	N/A	> 10		> 5	> 10	>10
	Steep slopes	> 50		> 50		> 50		> 50	N/A	> 50		> 50	> 50	>50
Costs ^c	Construction	\$-\$		\$-\$		\$\$-\$\$\$		\$\$	\$\$\$	\$-\$		\$-\$	\$	\$
	O & M (small)	\$\$-\$\$\$		\$\$-\$\$\$		\$\$-\$\$\$		\$\$	\$-\$	\$\$-\$\$\$		\$\$	\$-\$	\$-\$
	O & M (med.)	\$-\$\$ ^d		\$-\$		\$\$		\$-\$	\$-\$	\$\$		\$-\$	\$-\$	\$-\$
	O & M (large)	\$-\$\$ ^d		\$-\$		\$-\$		\$-\$	\$-\$	\$-\$		\$-\$	\$-\$	\$-\$

a. Typically permeable pavements are designed to treat direct rainfall, but, if located outside the Edwards Aquifer Recharge, Contributing, or Transition Zones, a 1:1 drainage area to permeable pavement area ratio can be accommodated with adequate maintenance. b. For tank outlet and overflow. c. Costs are relative, can vary project to project, and are generalized; for more specific cost information, see Appendix G. d. Based on necessary regular landscape maintenance already required. e. Pollutant removal performance is based on facilities constructed per design specifications in Appendix B.

3.8 Treatment Train Design

Treatment trains can be an effective method to treat stormwater runoff by combining BMPs in series. The combination of BMPs allows the designer to maximize pollutant removal while also providing flow and volume reduction. The benefits of combining several BMPs into a treatment train for a developer include increased flexibility for laying out BMPs within a development and incorporating smaller BMPs where space is limited.

Treatment train systems may be used to fit runoff treatment onto space constrained properties while at the same time achieving pollutant removal goals. Space constraints are usually the result of a combination of site layout, natural topography and other site-specific factors (tree locations, driveway cuts, etc.). Treatment trains allow several small BMPs to handle the water quality volume instead of trying to fit a single large BMP on a site. For example, adding supplemental small BMPs in green areas already included in the land plan (filter strips in medians, bioretention in parking lot islands, rain barrels in planter beds, etc.) can allow the overall treatment goal to be achieved without modifying the land plan to accommodate a single large BMP. Subsequent BMPs may provide an opportunity to address the overflow or bypass for that BMP.

The process of designing a treatment train is similar to designing a single BMP; however, the processes for calculation of treatment volume and pollutant removal as well as sizing BMPs should be adjusted. The development of a treatment train design is an iterative process and primarily depends on site conditions (such as space requirements and amount of runoff generated), cost, and local and state requirements (where these exist).

3.8.1 LID BMPs for Treatment Trains

All BMPs as described in [Section 3.7](#) may be used in configuring an effective treatment train approach including pre-treatment and/or conveyance practices that are not considered standalone BMPs. [Section 3.3](#) of this manual provides a discussion of BMP unit processes.

3.8.2 Selection and Layout for LID BMPs

[Sections 1.6.1](#) and [1.6.2](#) outline steps to perform a site assessment (steps 1-3), prepare a preliminary BMP design (steps 4-7), and complete a final design (steps 8-9). There are additional considerations that should be made during these steps for treatment train systems.

As outlined in step 3, conservation of natural vegetated areas can provide benefits within the development and should be considered as an asset to developments. However, conserving vegetated areas will not sufficiently treat stormwater runoff from a site. During Step 4, the designer should determine if a treatment train system is appropriate for the site. This step includes assessment of the spatial layout of the site using flow paths and natural drainage patterns. During this step, it may be determined that a series of distributed BMPs is an effective option based on the hydrologic flow paths and natural drainage, the site layout, and the opportunities for BMPs. This may also be verified during Step 5 which establishes clearing and grading limits. In addition, impervious area disconnection in Step 6 may help identify additional opportunities for BMPs within a treatment train system. For example, disconnecting a roof from the drainage system could enable capturing the runoff from the roof through a rain barrel or routing runoff through a swale to a downstream BMP. This step also encourages consideration of opportunities to minimize impervious surfaces.

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During Steps 7 and 8, the BMPs that would make up the treatment train should be identified and a preliminary layout determined. Additional information about the changes to the process for these steps is discussed below.

Step 7a: Review Pollutant Removal Process and Identify Pollutant Removal Practices

The purpose of this step is to create a list of BMPs that work together to remove the pollutants of concern identified in Step 1, to fit the hydrologic flow paths and site layout identified in Step 4, and to build on opportunities for impervious area disconnection and the conceptual designs from Step 6. Where possible, the designer should identify combination(s) of BMPs that best utilize the processes which address the identified pollutants of concern. Refer to [Chapter 3](#) and Appendix B of this manual for additional information about the effectiveness of specific BMPs and the selection of BMPs for an effective treatment train.

Once a list of BMPs has been created, review Steps 4-6 to assist in narrowing down BMP options based on site constraints which may include:

- available space;
- access for maintenance;
- limitations of infiltration related to soil type,
- soil contamination,
- depth to groundwater,
- presence of structures,
- utility conflicts, and/or depth to bedrock;
- regulatory requirements that affect the BMP volume or footprint, and
- compatibility with other site uses, such as green space requirements, public spaces, and structures.

Step 7b: Arrange Treatment Train Layout

Appendix B outlines a recommended approach to organize BMPs in a treatment train. The optimal treatment train system (summarized in Figure B-12-1 in Appendix B) includes four levels of treatment and incorporates multiple functions. Each level builds off the previous to implement a sequence that enhances the overall effectiveness of the treatment train. The most effective way to lay out the treatment train systems is to provide removal of large sediment and debris first, then filtration and infiltration, and finally biological and chemical treatment. Removal of large sediments through pretreatment can provide benefit for lot level BMPs, especially those that use filtration or infiltration. During selection of the BMPs, review Appendix B to understand the recommended sequence for the treatment train.

Step 8: Determine Approximate Size of LID BMPs

This section lays out a recommended process to size the BMPs in a treatment train system based on the water quality event. As described in Appendix A, there are separate processes for flow-based and volume-based BMPs. The designer should identify the most appropriate method to use based on the types of BMPs in the treatment train.

If the project area is within a region or municipality that has a defined water quality design event or a required water quality volume, the BMPs in the treatment train can be sized based on the local criteria. Otherwise, Appendix A of this manual outlines a process to estimate the water quality volume.

- 1) The first step to size BMPs within the treatment train is for the designer to delineate the drainage areas served by each of the BMPs and estimate the stormwater peak flow and capture volumes for the water quality event to be treated. This is discussed further in Appendix A for both volume-based and flow-based BMPs.
- 2) Next, the first BMP in the treatment train should be sized based on the available footprint or the water quality volume for the drainage area to that BMP. For flow-based BMPs, the BMP should be sized based on the peak flow for the design storm to that BMP. If space is limited or one or more BMPs are located within the same drainage area as another BMP, the water quality volume can be split between multiple BMPs. Refer to Appendix B to identify the layout and water quality volume for each LID BMP in the series.
- 3) The maximum available BMP footprint should be defined based on the layout identified in Step 7b and the designer should make sure that the available footprint is sufficiently large to produce the required water quality volume or to provide sufficient contact area for flow-based BMPs.
 - a. If the available footprint is not sufficient to achieve the defined water quality volume or flow, the portion of the water quality volume that is diverted through the overflow / bypass or that exceeds the capacity of the flow-based BMP should be captured and directed to the subsequent BMP.
 - b. If the BMPs include infiltration, the infiltration volume can be estimated and subtracted from the water quality treatment volume for subsequent BMPs in the treatment train.

For each subsequent BMP, the designer should consider the entire water quality volume or flow to that location, including that untreated from upstream BMP(s) and from any additional drainage area conveyed to that BMP downstream of the previous BMP(s). The designer should make sure that any additional volume from the water quality volume not treated in the upstream BMP(s) is treated by a downstream BMP. As noted in Step 3, volumes that were infiltrated in previous BMPs can be subtracted from the water quality volume to be treated at subsequent BMPs.

3.9 Maximizing Multiple Benefits of BMPs

The targets for treating stormwater runoff in the San Antonio River Basin can be expressed as either volume- or flow-based criteria. The volume-based requirement for an LID facility is to capture and treat the entire runoff volume from the volume-based design storm event. The flow-based requirement for a BMP facility is to treat the design runoff rate by applying the rainfall intensity-based water quality design storm. Methods for determining treatment volume and flow rates are provided in Appendix A for a range of design criteria.

LID BMPs can provide excellent ecosystem services and aesthetic value to stakeholders (see [Section 1.7](#) for an expanded discussion of the multiple benefits of LID). Bioretention areas can also enhance biodiversity and beautifying the urban environment with native vegetation. Permeable pavements inherently provide multi-use benefits because the facilities double as parking lots and transportation corridors, and rainwater harvesting allows for the provision of an alternative non-potable water source. The following components can be incorporated into BMPs to promote multi-use benefits:

- Simple signage or information kiosks to raise public awareness of stormwater issues and educate the public on the benefits of watershed protection measures or provide a guide for native plant and wildlife identification.
- Volunteer groups can be organized to perform basic maintenance as an opportunity to raise public awareness.
- Larger BMPs can be equipped with pedestrian cross-paths or benches for wildlife viewing.
- Sculptures and other art can be installed within the BMP and outlet structures incorporating aesthetically-pleasing colors, murals, or facades.
- Vegetation with canopy cover can provide shade, localized cooling (heat island mitigation), and noise dissipation.
- Enhanced pavement textures, colors, and patterns and other “complete streets” components can calm traffic, increase aesthetic appeal, enhance pedestrian safety, and draw attention to multi-use stormwater practices.
- Bird and butterfly feeders can be used to attract wildlife to the BMPs.
- Ornamental plants can be cultivated along the perimeter and in the bed of vegetated BMPs (invasive plants should be avoided).
- BMPs can function as irrigation beds for stormwater captured by other BMPs, such as stormwater cisterns or the reservoir layer of permeable pavement.
- Reuse of captured runoff can offset non-potable water supplies used for toilet flushing, car washing, swimming pools, street sweeping, and other uses.
- Permeable pavers can be selected to maintain the character of historic districts while providing stormwater management solutions.
- Incorporate creative downspout designs for small practices (rain chains).

3.10 References

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4. Execution Considerations

Permanent structural stormwater control BMPs require smaller operation and maintenance budgets over the design life when important life-cycle activities, including inspections and maintenance, are considered early in the planning and design process. Because post construction inspections and maintenance are essential to facility function, it is important to ensure that necessary equipment, access, and methods to complete maintenance and BMP evaluation tasks during the operation phase are considered during the design phase.

BMP execution can be complicated by problems stemming from design needs that are not understood, inexperienced contractors performing the construction, or inadequate operation and maintenance. Chapter 4 includes considerations for BMP construction observation, post-construction inspection, and operation and maintenance. It is recommended that the project manager include in the project specifications the considerations presented in this section.

4.1 BMP Construction

In this section, potential construction problems are reviewed so that LID BMP designers can improve designs and avoid future issues. Essential functions of permanent LID BMPs (e.g. bioswale, wetland) can be deteriorated by common construction practices, such as compacted soils from heavy equipment, erosion and sediment build-up, or work performed in saturated conditions. Construction observation and inspections by a qualified inspector familiar with the functions of structural BMPs are recommended for quality control and assurance. As part of construction oversight, inspectors should ensure that the proper temporary erosion control practices are implemented in accordance with federal, state, and local regulations. Construction specifications might include the following measures to protect the permanent LID BMP (e.g. bioretention, permeable pavement) while construction operations are underway:

- Establish a protective zone around valued natural areas and trees that will be preserved.
- Minimize the use of heavy equipment, especially in areas where infiltration BMPs will be.
- Minimize soil disturbance and unprotected exposure of disturbed soils.
- Expose only as much area as needed for immediate construction.
- As areas are cleared and graded, apply appropriate erosion controls to minimize soil erosion.
- Protect stormwater infiltration BMPs from unwanted sedimentation during the construction phase.
- Provide a temporary outlet to convey runoff down slope with sediment traps at outlets and inlets.
- Minimize the movement of soil into the drainage system.
- Use sediment and erosion protection practices early in the site clearing and grading process to reduce the sediment-laden runoff reaching soils intended for future infiltration.

- Protect future infiltration facilities from sediment from adjacent properties.

Sensitive areas that need to be protected should be delineated before grading and clearing starts. It is best to indicate such restrictions on the site plan. Areas of existing vegetation that are planned for preservation should be clearly marked with a temporary fence. If trees have been designated for preservation, equipment should be prohibited within the drip line to prevent root and trunk damage. Trenching and excavating should not occur within the drip line, and trenches outside but adjacent to the drip line should be filled in quickly to avoid root drying.

4.1.1 Temporary Erosion and Sediment Control Practices

Soil-disturbing activities at the construction site can increase erosion and sediment risks. Apply an effective combination of temporary soil erosion and sediment controls to minimize the discharge of sediments from the site or into a stormwater drainage system or natural receiving water. TCEQ's *Complying with the Edwards Aquifer Rules Technical Guidance on Best Management Practices* provides detailed specifications for erosion and sediment control BMPs that are applicable to all construction sites (TCEQ 2005). Properly applying the temporary controls (both on-site and for drainage from off-site parcels with the potential to contribute sediment) is essential and can help preserve the long-term capacity and functions of the permanent stormwater BMPs. Inspection and maintenance of these temporary controls are required to ensure that they remain effective. These controls are in addition to the SWPPP measures that are required by the TCEQ's general NPDES permit to limit movement of sediment off a site.

Proper construction sequencing can reduce the risk of clogging by excessive accumulation of fine particles in the soil media layers. Designers should specify proper construction sequencing to minimize potential disturbance to LID structures. During construction, the extent of disturbed, exposed soils should be limited to reduce the risk of erosion by specifying the timing and extent of permanent vegetation establishment. Imported soil media should not be incorporated into BMPs until the drainage area has been stabilized. Soil media should not be installed until at least the first course of pavement has been set for roads and parking lots, which minimizes the amount of fines washed from the bedding layers into the BMP. A geotextile liner might not be sufficient to prevent fines from migrating into and clogging the soil media layer; for that reason, proper construction sequencing is crucial. Figure 4-1 and Figure 4-2 are examples of the fines that can accumulate and clog the soil media if proper construction sequencing is not followed.



Figure 4-1. Example of a bioretention area installed before permanent site stabilization with the inset photo showing the clay layer clogging the mulch surface. Source: North Carolina State University Department of Biological and Agricultural Engineering



Figure 4-2. Accumulated fines layer as a result of improper construction sequencing. Source: North Carolina State University Department of Biological and Agricultural Engineering

4.1.2 BMP Construction Inspection

It is essential to inspect all construction phases to ensure that BMPs are properly installed, especially when critical elements of a structural BMP are being installed, such as inverts, inlets, outlets, overflow, and underdrains. In the design notes, designers should stipulate whether the type of materials specified cannot be substituted because they might not perform as well (e.g., engineered media). If an element of a structural BMP system was not properly constructed or the wrong materials were used, the entire system could fail to achieve the desired stormwater benefits. Construction inspection should be performed by the design professional of record or a certified inspector with specific training and experience on BMP construction.

Accurate grading of stormwater infrastructure, including structural BMPs and hardscape areas, is critical to ensure gravity drainage and the desired BMP functions. Research has shown that structural practices with insufficient storage capacity (whether because of carelessness when specifying outlet structure elevations or inaccurate grading) might not perform the functions for which they were installed (Brown and Hunt 2011; Luell et al. 2011). The designer and contractor should work together to ensure that the project is correctly built to plan. Spot elevations of critical components should be available from construction plans to verify construction. If necessary, arrange for appropriate contractor training before starting a BMP construction project and make training available on demand during construction. It is important to perform field survey during construction and verify that the designed average ponding depth has been provided (Figure 4-3); simply measuring the height of the outlet structure relative to the ground surface is inadequate (Wardynski and Hunt 2012).

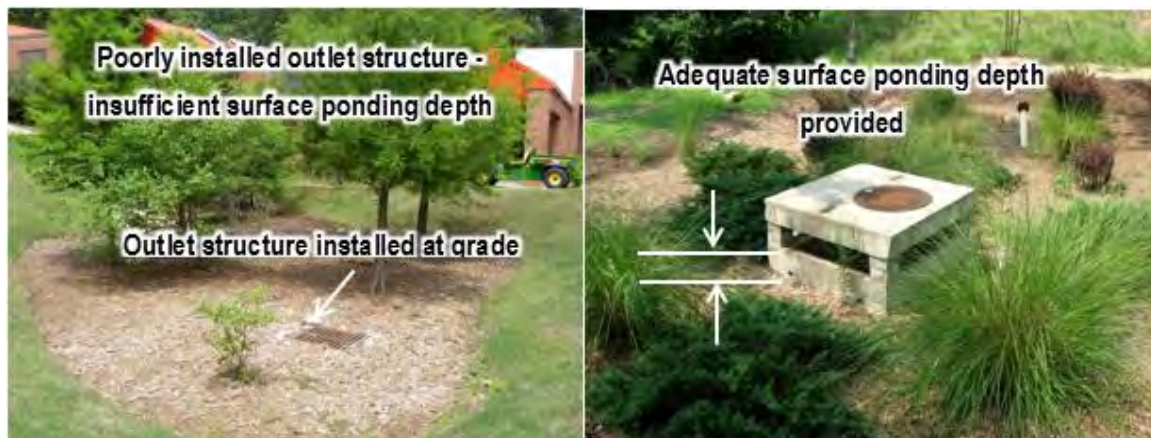


Figure 4-3. Accurate grading and outlet elevations must be provided to achieve intended hydrologic and water quality functions. Source: Tetra Tech

Construction activities inherently compact site soils, which can dramatically decrease infiltration rates. Contractors should be clearly instructed to minimize compaction by using tracked equipment, excavating the last 12 inches using a toothed excavator bucket, and by minimizing the number of passes over the proposed subgrade while operating the equipment outside of the BMP area where possible (Figure 4-4). Earth moving activities should take place during dry conditions, to the extent practicable, to reduce the occurrence of smearing the soil surface, which can reduce soil permeability. To mitigate compaction and partly restore infiltration capacity (for practices that are intended to infiltrate), the subgrade should be treated by scarification or ripping to a depth of 9–12

inches (Figure 4-5; Tyner et al. 2009). A soil test may be required after scarifying to verify that infiltration rates have been restored. If the design infiltration rate is not restored after scarifying or ripping, trenches can be installed along the subgrade to enhance infiltration. Trenches should be constructed 1-foot-wide by 1-foot-deep on 6-foot centers and filled with a 0.5-inch layer of washed sand, then topped off with pea gravel (Tyner et al. 2009).

Many urban sites, especially retrofit conditions, have little or no organic material in the soil structure because they have been paved over for many years. Excavation also tends to unearth relatively infertile subsoils. If engineered soil is not specified, a soil test (<http://soiltesting.tamu.edu/files/urbansoil.pdf>) is recommended to determine the suitability of site soils for plant growth, especially for practices where vegetation will be planted in on-site excavated soils (such as stormwater wetlands). Amendment with 2 to 4 inches of topsoil could be required to improve plant establishment. Appendix B provides information on specific media requirements to prepare the BMP site for planting. Consultation with the landscape architect is recommended to verify rooting depths and establish construction guidance for the landscape contractor. The planting plan should also include guidance on the appropriate time of year to plant trees, shrubs and grass to reduce plant stress during establishment.



Figure 4-4. Heavy equipment being operated outside the excavated area to prevent compaction. Source: Tetra Tech



Figure 4-5. Subsoil compaction in an infiltration practice being mitigated by ripping the grade to a depth of 12 inches. Source North Carolina State University Department of Biological and Agricultural Engineering

4.2 Post Construction BMP Inspection

To maintain the effectiveness of structural BMPs, regular inspection is essential. Generally, BMP inspection and maintenance can be categorized as routine and as as-needed. Routine activities, performed regularly (e.g., monthly), ensure that the BMP is in good working order and continues to be aesthetically pleasing. Routine inspection is an efficient way to prevent potential nuisance situations from developing and to reduce the need for repair or maintenance. Routine inspection also reduces the chance of degrading the quality of the effluent by identifying and correcting potential problems regularly. Property maintenance personnel should be instructed to inspect BMPs during their normal routines.

In addition to routine inspections, as-needed inspection and maintenance of all BMPs should be performed after any event or activity that could damage the BMP, particularly after every large storm event. Post-storm inspections should occur after the expected drawdown period for the BMP, when the inspector can determine if the BMP is draining correctly.

Checklists with maintenance specifications and requirements are provided in Appendix F. In general, individual BMPs can be described with minimum performance expectations, design criteria, structural specifications, date of implementation, and expected life span as provided in [Chapter 3](#) and detailed in Appendix B. Recording such information will help the inspector determine whether a BMP's maintenance schedule is adequate or requires revision and will allow comparison between the intended design and the as-built conditions. Checklists also provide a useful way for recording and reporting whether major or minor renovation or routine repair is needed. The effectiveness of a BMP might be a function of the BMP's location, design specifications, maintenance procedures, and performance expectations. Inspectors should be familiar with the characteristics and intended function of the BMP so they can recognize problems and know how they should be resolved.

Routine and as-needed BMP inspections consist of technical and non-technical activities as summarized below:

- Inspect the general conditions of the BMP and areas directly adjacent.
- Maintain access to the site including the inlets, side slopes (if applicable), forebay (if one exists), BMP area, outlets, emergency spillway, and so on.
- Examine the overall condition of vegetation.
- Eliminate any possibility of public hazards (vector control, unstable public access areas).
- Check the conditions of inflow points, pretreatment areas (if they exist), and outlet structures.
- Inspect and maintain the inlet and outlet regularly and after large storms.
- Ensure that the pretreatment areas meet the original design criteria.
- Check the encroachment of undesirable plants in vegetated areas. This could require more frequent inspections in the growing season.
- Inspect water quality improvement components. Specifically, check the stormwater inflow, conveyance, and outlet conditions.
- Inspect hydrologic functions such as maintaining sheet flow where designed, ensuring functional pretreatment, maintaining adequate design storage capacity, and verifying proper operation of outlet structures.
- Check conditions downstream of the BMP to ensure that flow is properly mitigated below the facility (e.g., excessive erosion, sedimentation).

In every inspection, whether routine or as-needed, the inspector should document whether the BMP is performing correctly and whether any damage has occurred to the BMP since the last inspection. Ideally, the inspector will also identify what should be done to repair the BMP if damage has occurred. Documentation is very important in maintaining an efficient inspection and maintenance schedule, providing evidence of ongoing inspection and maintenance, and detecting and reporting any necessary changes in overall management strategies.

4.3 BMP Operation and Maintenance

The major goal of BMP operation and maintenance (O&M) is to ensure that the BMP is meeting the specified design criteria for stormwater flow rate, volume, and water quality control functions. If structural LID systems are not properly maintained, BMP effectiveness can be reduced, resulting in water quality impacts. The design professional should provide an O&M manual with the construction documents or final as-built plans. It is important that routine maintenance and any need-based repairs for a structural BMP be completed according to schedule or as soon as practical after the problem is discovered. Deferred BMP maintenance could result in detrimental effects on the landscape and increased potential for water pollution and local flooding.

Training should be included in program development to ensure that maintenance staff has the proper knowledge and skills. The SARA and Bexar County have developed an annual inspection and maintenance certification course with training available annually. Most structural BMP

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maintenance work—such as mowing, removing trash and debris, removing sediment, and the like—is non-technical and is already performed by property maintenance personnel. More specialized maintenance training might be needed for more complex systems. General maintenance activities for the two major categories of structural facilities (filtration and infiltration) are as follows:

Infiltration BMPs

- Mowing and maintaining upland vegetated areas if applicable.
- Cleaning and removing debris after major (around 0.5 inch or greater) storm events.
- Cleaning out accumulated sediment.
- Repairing or replacing stone aggregate.
- Maintaining inlets and outlets.
- Removing accumulated sediment from forebays or sediment storage areas when 50 percent of the original volume has been lost.
- Maintaining porosity of the substrate.

Biofiltration and Filtration BMPs

- Removing trash and debris from control openings.
- Watering and mowing vegetated areas.
- Removing all dead and diseased vegetation and replacing as necessary.
- Stabilizing eroded side slopes and bottom by replanting.
- Repairing erosion areas by regrading or adding flow dispersion or energy dissipation.
- Mulching void areas if needed.
- Maintaining inlets and outlets.
- Repairing leaks from the sedimentation chamber or from deteriorating structural components.
- Cleaning out accumulated sediment from the filter bed once depth exceeds approximately one-half inch or when the filter layer no longer draws down within 24 hours.

In regions where dry and wet seasons are clearly distinguished, as is the case in Bexar County, conducting special maintenance activities before spring and fall storms can be very helpful to prevent increased erosion. If a BMP does not meet the specified design criteria, it must be repaired, improved, or replaced before a wet season starts. Any accumulated sediment and trash should be removed to maximize the performance of the facility throughout the following wet season. Detailed

descriptions of operation and maintenance for specific types of LID BMPs are in Appendix B, and general maintenance issues are presented in the following sections.

4.3.1 Bioretention

Maintenance activities for bioretention units should be focused on the major system components, especially landscaped areas. Bioretention landscape components should blend over time through plant and root growth, organic decomposition, and natural soil horizon development. Those biological and physical processes over time will lengthen the facility's life span and reduce the need for extensive maintenance. Refer to [Chapter 3](#) and Appendix B for design guidance on soil media and plant selection.

Irrigation of vegetated areas might be needed during the plant establishment period but fertilizer and pesticide application should be minimized. In periods of extended drought, temporary supplemental irrigation could be used to maintain plant vitality. Irrigation frequency will depend on the season and type of vegetation. Properly selected vegetation will go dormant during dry periods but will revitalize when rainfall occurs. Native plants generally require less irrigation than non-native plants and should be incorporated into site designs where feasible. Native plants are also less susceptible to disease and require fewer pesticides. Controlled drainage can also be used to manage soil moisture by selectively elevating the underdrain outlet in dry periods; this will result in greater soil moisture retention between rainfall events. The underdrain outlet should always be no less than 18 inches below the soil surface to prevent saturation of the plant rooting zone.

Routine maintenance should include a twice-yearly evaluation of the trees and shrubs and subsequent removal of any dead or diseased vegetation (USEPA 1999). Corrective actions should be taken to remove areas with standing water for more than 24 hours in the BMP to restore proper infiltration rates and prevent mosquito and other vector habitat formation. An Integrated Pest Management (IPM) Plan should be developed to minimize the use of broad-spectrum pesticides that may kill beneficial insects that feed and pollinate the native vegetation. To maintain the treatment area's appearance, it might be necessary to prune and weed. Replace mulch for aesthetics or when erosion is evident. Depending on pollutant loads, soil media might need to be replaced within 5 to 10 years of construction (USEPA 2000).

Stabilizing the area around the bioretention area can reduce maintenance by reducing the sediment flowing into the BMP. Figure 4-6 shows an example of how a bioretention area can clog with sediment if the surrounding area is not properly stabilized. Proper design of inlet systems can also reduce maintenance requirements by removing trash and other gross solids keeping floatables out of the bioretention area and, in some cases, in the street for easy collection and removal by a street sweeper or maintenance crew as shown in Figure 4-7.



Figure 4-6. Bioretention area clogged with sediment. Source North Carolina State University Department of Biological and Agricultural Engineering



Figure 4-7. Inlet sump to remove gross solids. Source: Portland Bureau of Environmental Services

4.3.2 Bioswale

The maintenance objectives for bioswale systems consist of retaining stormwater conveyance capacity, runoff volume control, and pollutant removal efficiency. To meet those objectives, it is important to maintain a consistent ground cover in the bioswale. Maintenance activities involve replacing or redistributing mulch, mowing (where appropriate), weed control, irrigating during drought conditions, reseeding or sodding bare areas, and clearing debris and blockages. Manage vegetation on a regular schedule during the growth season to maintain adequate coverage. Accumulated sediment should also be removed manually to avoid concentrated flow. During the plant establishment period, minimize fertilizer and pesticide application. Irrigation might be needed to maintain plant vitality, especially during plant establishment or in periods of extended drought. Irrigation frequency will depend on the season and type of vegetation. Properly selected vegetation will go dormant during dry periods but will revitalize when rainfall occurs. Native plants require less irrigation than non-native plants and should be incorporated into site designs where feasible. Native plants are also less susceptible to disease and require fewer pesticides. An IPM Plan should be developed to minimize the use of broad-spectrum pesticides that may kill beneficial insects that feed and pollinate the native vegetation. Bioswales should be designed to minimize flow velocity and prevent the type of erosion shown in Figure 4-8. If excessive flows are identified as the cause of the problem, they should be diverted using the design methods identified in Appendix B to prevent erosion and minimize maintenance.



Figure 4-8. Erosion caused by excessive flows in a bioswale. Source: Tetra Tech

4.3.3 Planter Box

General maintenance requirements for planter boxes are the same as the routine periodic maintenance of other landscaped areas or bioretention BMPs. The primary maintenance requirement for planter boxes is to inspect the vegetation and soil media. Regularly remove any accumulated trash and sediment in the device, especially after large storms, or as needed during periods where overhanging vegetation is dropping leaves. Inspect soils to evaluate root growth and mitigate channel formation or uneven distribution in the soil media.

4.3.4 Sand Filter

The primary maintenance requirement for sand filters is to remove trash, accumulated sediment, and media contaminated with hydrocarbons. If the filter does not drain within 48 hours, or if sediment has accumulated to a depth of 6 inches, the top layer (1–3 inches) of sand (media) must be replaced. TCEQ (2005) provides similar recommendations for sand filters in the Edwards Aquifer Recharge and Contributing zones.

4.3.5 Permeable Pavement

The primary maintenance requirement for permeable pavement consists of regular inspection for clogging (Figure 4-9). The main goal of the maintenance program is to prevent clogging by fine sediment particles, which should be accomplished through a combination of preventative tasks including timely removal of debris (leaf litter, acorns, grass clippings, mulch, and such) and stabilizing surrounding areas. To maintain the infiltrative capacity of permeable pavements, vacuum sweeping should be performed a minimum of twice a year. Frequency of vacuum sweeping should be adjusted according to the intensity of use and deposition rate on the permeable pavement surface. Settled paver block systems might require resetting. When modular pavements incorporate turf into their void area, normal turf maintenance practices, including watering, fertilization, and mowing might be required (FHWA 2002).



Figure 4-9. Plant growth and debris buildup indicate that permeable pavement is clogging. Source Tetra Tech

For proper performance, maintenance staff must ensure that stormwater is infiltrating properly and is not standing or pooling on the surface of the permeable pavement for extended periods of time. Standing water can indicate clogging of the pavement void space and vacuuming is necessary to restore infiltration. If ponding still occurs, inspect/replace the media sublayer and check the underdrain for blockage.

4.3.6 Stormwater Cisterns

General maintenance activities for cisterns and rain barrels are easily performed by maintenance personnel or homeowners. The Texas A&M AgriLife Extension Service's Rainwater Harvesting (2008) guide provides maintenance recommendations to homeowners. The primary maintenance requirement is to inspect the tank and distribution system and test any backflow-prevention devices (See Appendix B). Rain barrels require minimal maintenance several times a year and after major storms to prevent any clogging. Cisterns require inspections for clogging and structural soundness twice a year, including inspection of all debris and vector control screens. If a first-flush diverter is used, it should be dewatered and cleaned between each storm event that fills the diverted storage pipe. Self-cleaning filters and screens, such as the ones shown in Figure 4-10, can help prevent debris from entering the cistern and reduce maintenance. Accumulated sediment in the tank must be removed at least once a year. The *Texas Manual for Rainwater Harvesting: Third Edition* (TWDB 2005) provides additional measures for systems designed for potable water supply or drip irrigation applications.



Figure 4-10. Self-cleaning inlet filters. Source: Tetra Tech

4.3.7 Stormwater Wetlands

Maintenance activities for wetlands involve removing accumulated sediments and ensuring that plant distribution and flow paths remain as designed. Constructed wetlands built for the express purpose of stormwater treatment are not considered jurisdictional wetlands in most regions of the country, but designers should check with their wetland regulatory authorities (USACE Region 6) to ensure this is the case (Virginia 2011). Bedload sediment tends to be concentrated in pretreatment areas and forebays; it is important that this sediment not enter the rest of the wetland, because accumulated coarse sediments can affect the growing conditions of the wetland plants or change flow paths and design depths. Sediment removal should be performed more frequently, or



Figure 4-11. Outlet elevation varied with weir boards. Source: Tetra Tech



Figure 4-12. Outlet with a trash rack. Source North Carolina State University Department of Biological and Agricultural Engineering

pretreatment and forebay areas should be resized, if excessive sediment is found outside designated areas. Sediment removal in vegetated areas should be performed carefully to prevent damage to plants. Depending on the land use of contributing areas, sediment testing might be necessary to determine if accumulated pollutants require special disposal. Wetlands should be inspected according to the schedule provided in Appendix B or as-needed after storm events. Inspectors should refer to a map of the wetland as designed to determine if the types and distribution of plants are as intended. Undesirable species should be identified and removed as needed. If plant die-off has occurred, reevaluate growing conditions and select replacement plants adapted to those conditions. Ensure that design depths and flow paths are maintained, and remove trash and debris that has accumulated in or around the wetland. Outlets should be designed such that the water level in the wetland can be varied for establishment periods and maintenance using a variable outlet control similar to that shown in Figure 4-11. A minimum orifice size should be considered and a trash rack, similar to the one shown in Figure 4-12, can be used to minimize and limit clogging. Details on outlet design are provided in Appendix B.

4.3.8 Green Roofs

Operation and maintenance of stormwater management (green, blue, brown, biodiverse) roofs primarily involves maintaining drainage structures and vegetation. Roof drains, gutters, and downspouts should be routinely inspected for clogging. If excess material tends to build up around drainage structures, the source of the problem should be remediated. To prevent vegetation from growing too close to roof drains and to identify roof drains for maintenance personnel, a circle of white gravel can be placed around the drain to designate a *no plant zone* as shown in Figure 4-13. Vegetation should be inspected periodically, especially during prolonged dry weather, to determine irrigation needs and general health. Properly selected vegetation will go dormant during dry periods but will revitalize when rainfall occurs. Periodic inspection of growing media and underlying drainage layers might also be necessary for extensive green roofs to ensure that reservoir layers are not filling with sediment deposits or extensive root networks. Intensive green roofs could require pruning and mowing at the end of the growing season, depending on vegetation type. Roofs require

appropriate health and safety protocols for fall protection. Maintenance staff and designers should consult their Safety Officer or OSHA guidance for proper equipment and safety plans. Foot traffic should be limited, to the extent practicable, to reduce plant damage and preserve aesthetic design goals. Additional guidance on roof design, maintenance, and leak detection is available from *Design Guidelines and Maintenance Manual for Green Roofs in the Semi-Arid and Arid West* (Tolderlund, 2010).



Figure 4-13. White gravel indicates a no plant zone for a green roof, Raleigh, North Carolina. Source City of Raleigh

4.3.9 Extended Detention Basins

Maintenance activities for EDBs involve removing accumulated sediments and ensuring that plant distribution and flow paths remain stable, clear of sediment accumulation, and able to perform as designed. Visual monitoring should be performed after major storm events during stabilization and on a regular basis after stabilization. The designer must consider maintenance requirements in the design of the basin. If properly designed and constructed, bedload sediment should be concentrated in pretreatment areas and forebays. It is important that sediment be prevented from being discharged to the rest of the basin. Accumulated sediments can be resuspended during subsequent storms, affect the growth of vegetation, and change flow paths and design depths. Sediment removal should be performed more frequently, or pretreatment and forebay areas should be resized if excessive sediment is found within the forebay, trickle channel, or outside designated areas. Sediment removal in vegetated areas should be performed carefully to prevent damage to plants and destabilization of soils. Depending on the land use of contributing areas, sediment testing might be necessary to determine if accumulated pollutants require special disposal. EDBs should be inspected according to the schedule provided in Appendix B or as-needed after storm events.

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Inspectors should refer to the design plans of the EDB to determine if the types and distribution of plants are established as designed. Undesirable species should be identified and removed as needed. If plant die-off has occurred, the growing conditions should be re-evaluated and replacement plants selected that are adapted to those conditions. The inspector should ensure that design depths and flow paths are maintained and remove trash and debris that has accumulated in or around the EDB. A minimum orifice size should be considered and a trash rack, similar to the one shown in Figure 4-14, must be used to minimize and limit clogging. A properly sized and attached trash rack should prevent debris and litter from entering and clogging pipes and orifices. Ideally all outlet structures and trash racks should be located on or near a basin embankment to allow for easy maintenance and debris removal. Trash racks should also be large enough so that partial clogging will not have a hydraulic impact on the outlet structure. Details on outlet and trash rack design are provided in Appendix B.



Figure 4-14. Sloped trash rack with parallel wing walls. Source: Urban Drainage Flood Control District

4.4 BMP Monitoring

Performance monitoring of stormwater BMPs is an important component of LID implementation programs. Monitoring provides the BMP designer and regulator with a mechanism to validate certain design assumptions and to quantify compliance with pollutant-removal performance objectives. Specific monitoring objectives should be considered early in the design process to ensure that LID practices are adequately configured for monitoring. Detailed monitoring guidance provided by the U.S. EPA is listed in this chapter's references section (USEPA 2012). The TCEQ also provides templates and guidance on Quality Assurance Project Plans (QAPP) for Nonpoint Source Projects through their website (TCEQ 2013). The instrumentation and monitoring

configuration will vary from site to site, but the general principles presented in sections 4.4.1 and 4.4.2 below should be considered.

4.4.1 Monitoring Hydrology

An inlet/outlet sampling setup is suggested as the most effective monitoring approach to quantify flow and volume in stormwater BMPs. The runoff source and type of BMP will dictate the configuration of inflow monitoring. A weir or flume is typically installed at the inlet of BMPs that receive concentrated, open channel flow (i.e., from a pipe, curb cut, or a swale as shown in Figure 4-15, Figure 4-16, and Figure 4-17). Often a baffle or weir box is used in conjunction with weirs to still flows for more precise readings, as shown in Figure 4-18. The height of water flowing over the structure is automatically recorded (typically with a pressure transducer, such as a bubbler), which is used to calculate the rate of inflow. By integrating the flow rate over each monitored time step, total runoff volume for each storm event can be calculated. When runoff enters a BMP via conduit, weirs or weir boxes can still be used for monitoring, but acoustic Doppler velocimeters (ADV) might be preferred. ADVs measure flow by recording the velocity and depth of water and will provide more accurate results if inflow conduits are expected to flow full (pressure flow), although some models require heavy turbidity to attain accurate readings. Outflow can be monitored using similar techniques as inflow by installing a weir or ADV at the point of overflow/outfall.



Figure 4-15. Inflow pipe to bioretention area equipped with compound weir and bubbler for flow measurement. Water quality sampling tube and strainer are visible inside pipe. Source: Tetra Tech



Figure 4-16. Inlet curb cut with a v-notch weir. Source: Tetra Tech



Figure 4-17. Outlet of a roadside bioretention pop-out equipped with a V-notch weir for flow monitoring. Source: Tetra Tech



Figure 4-18. Underdrains from permeable pavement equipped with 30° V-notch weir boxes and samplers for flow and water quality monitoring. Source: Tetra Tech

It is critical during hydrologic monitoring that no downstream tailwater interfere with the monitoring device, or false readings will be generated. To prevent tailwater effects at the inlet, the invert of the inflow pipe should be well above the expected temporary ponding depth of the BMP (Figure 4-19)—this is typically not possible with offline BMPs because the weir elevation controlling the bypass is at the maximum elevation in the BMP. Additional freeboard between the inlet and the maximum expected water depth should be provided to prevent the inlet monitoring device from being inundated by tailwater from the BMP (Figure 4-20). The same considerations should be addressed when monitoring outflow by ensuring that the receiving storm drain network has sufficient capacity to convey high flows such that no tailwater inundates the outflow monitoring device. Figure 4-21 shows an example of potential monitoring points.



Figure 4-19. Example of a bioretention underdrain outlet with sufficient drop to install a flow monitoring weir without encountering tailwater. Source: Tetra Tech



Figure 4-20. Poorly installed H-flume at the inlet to a bioretention area in which the invert of the weir is too low and tailwater from the bioretention will interfere with measurement. Source: Tetra Tech

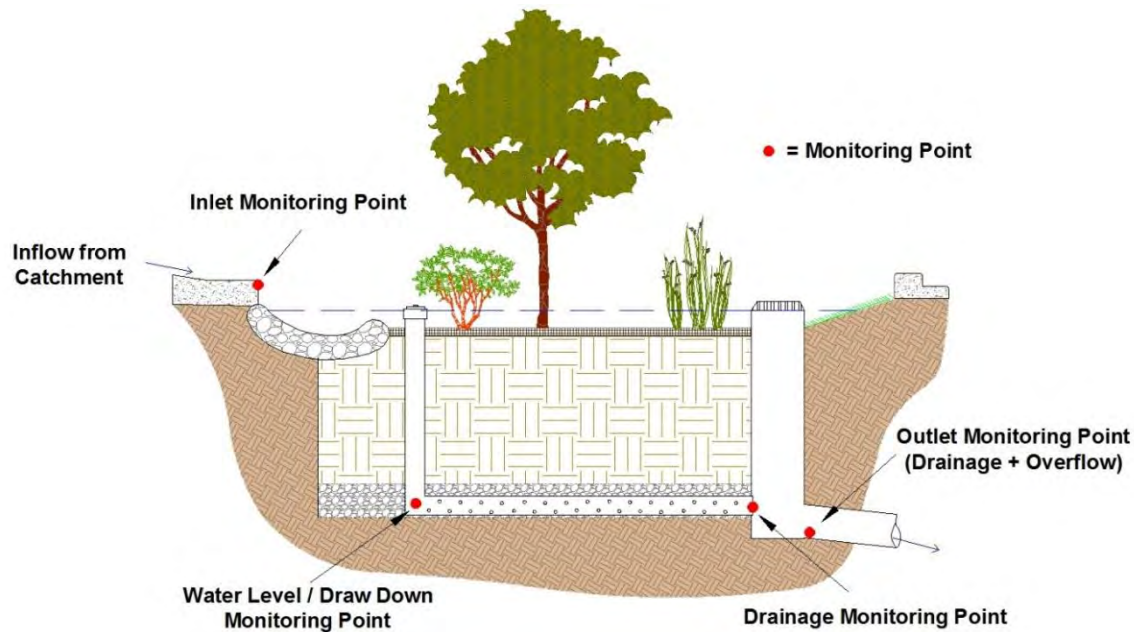


Figure 4-21. Schematic showing potential monitoring points

In addition to monitoring inflow and outflow, rainfall should be recorded on-site. Rainfall data can also be used to estimate inflow to BMPs that receive runoff only by sheet flow or direct rainfall (i.e., permeable pavement or green roofs). The type of rain gauge depends on monitoring goals and frequency of site visits (USEPA 2012). An automatic recording rain gauge (i.e., tipping bucket rain gauge), used to measure rainfall intensity and depth, is often paired with a manual rain gauge for data validation (Figure 4-22). For more advanced monitoring, weather stations can be installed to simultaneously monitor relative humidity, air temperature, solar radiation, and wind speed. These parameters can be used to estimate evapotranspiration.



Figure 4-22. Manual (left) and tipping bucket (right) rain gauges. Source: Tetra Tech

Water level (and drawdown rate) is another useful hydrologic parameter. Depending on project goals, perforated wells or piezometers can be installed to measure infiltration rate and drainage. Care should be taken when installing wells to ensure that runoff cannot enter the well at the surface and *short circuit* directly to subsurface layers; short circuiting can result in the discharge of untreated runoff that has bypassed the intended treatment mechanisms. It might be useful to pair soil moisture sensors with water level loggers in instances where highly detailed monitoring performance data are required (such as for calibration and validation of models).

4.4.2 Monitoring Water Quality

Although hydrologic monitoring can occur as a standalone practice, water quality data must be paired with flow data to calculate meaningful results of constituent loading. Flow-weighted automatic sampling is the recommended method for collecting samples that are representative of

the runoff event and can be used to calculate pollutant loads (total mass of pollutants entering and leaving the system). Simply measuring the reduction in constituent concentrations (mass per unit volume of water) from inlet to outlet can provide misleading results because it does not account for load reductions associated with infiltration, evapotranspiration, and storage.

Influent water quality samples are typically collected just upstream of the inlet monitoring device (weir box, flume, and such) just before the runoff enters the BMP. The downstream sampler should be at the outlet control device just before the overflow entering the existing storm drain infrastructure. A strainer is usually installed at the collecting end of the sampler tubing to prevent large debris and solids from entering and clogging the sampler. Automatic samplers should be programmed to collect single-event, composite samples according to the expected range of storm flows. Depending on the power requirements, a solar panel or backup power supply might be needed.

In addition to collecting composite samples, some water quality constituents can be monitored in real time. Some examples include dissolved oxygen, turbidity, conductivity, and temperature.

4.4.3 Sample Collection and Handling

Quality assurance and quality control protocols for sample collection are necessary to ensure that samples are representative and reliable. The entire sample collection and delivery procedure should be well documented in the QAPP, including chain of custody (list of personnel handling water quality samples) and notes regarding site condition, time of sampling, and rainfall depth in the manual rain gauge. Holding times for water quality samples vary by constituent, but all samples should be collected and delivered to the laboratory on ice as soon as possible (typically 6 to 24 hours) after a rainfall event. Some water quality constituents require special treatment upon collection, such as acidification, to preserve the sample for delivery. Appropriate health and safety protocol should always be followed when on-site, including, for example, using personal protective equipment such as safety vests, nitrile gloves, and goggles.

4.5 Reducing Project Costs

Implementing more natural stormwater management practices with less reliance on conventional, conveyance focused designs can reduce overall project costs (USEPA 2007). In addition, such facilities can help provide social, environmental, and economic benefits (CNT 2010). Using an LID approach can be one of the more effective ways to reduce construction costs to minimize the effects on the existing stormwater collection systems. Long-term operation and maintenance cost reduction goals can be achieved when more naturalized approaches are used because the native vegetation is adapted to the local weather conditions requiring less irrigation and other maintenance, resulting in effective treatment with minimal maintenance.

Installing stormwater BMPs at upstream areas can provide considerable cost saving opportunities for the downstream areas. Any potential increase in costs to implement stormwater BMPs might be offset by reduced costs associated with flood controls, pollution mitigation, and public health issues in the watershed-scale evaluation.

Implementing green parking techniques like applying permeable pavement and other alternative transportation options can reduce stormwater management costs as well. Minimizing stall dimensions and encouraging shared parking can result in considerable construction cost savings.

Relative cost-effectiveness of a structural BMP can be established on the basis of planning, design, and construction costs. Annual operation and maintenance expenses for the expected life of the management practice should also be included in cost-effective assessments. Appendix G provides cost guidance for construction and maintenance activities that can be used to develop planning level cost estimates. Such cost information and the use of specified removal efficiencies for a structural BMP can be a useful tool when implementing pilot projects to determine costs and benefits for stormwater controls at a larger, citywide scale.

4.6 Demonstration Projects

Demonstration or pilot projects provide valuable information to the planning, design, and maintenance communities. Features that were done correctly and those that were done incorrectly can serve as learning opportunities and provide essential information on successful components and components that must be improved through all phases of design, construction and post-construction. Information gathered can also provide further understanding and acceptance for non-municipal entities through the application of LID BMPs. That understanding can reduce concerns about risk as experience and technical knowledge is gained from implementing demonstration projects.

Demonstration projects provide concrete examples of how LID BMPs can be implemented in an environment. Successful projects reduce uncertainty about whether the LID BMPs will produce the desired result in a particular setting. Demonstration projects can offer overall guidelines and examples for the designs, materials, and implementation of structural BMPs and inform site planning,

design, and development strategies associated with integrating LID management practices. Those projects can be used as guidelines for performance evaluations, long-term operation and maintenance needs, and cost estimations for individual or integrated LID treatment trains. The projects also allow engineers and designers to verify proper function and maintenance of the systems.

Demonstration projects can illustrate how stormwater LID BMP strategies might be incorporated into other areas of site development strategies. Alternative transportation options to enhance safer street environments, such as traffic safety and control, can improve stormwater quantity and quality problems. Demonstration projects can also be useful in forensic engineering into systems that fail or do not meet quality or flow-control expectations. Improvements can then be made on future



Figure 4-23. Rain garden incorporated into Better Block street revitalization project. Source: Bender Wells Clark Design

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designs through the iterative, adaptive management approach common at that stage of understanding according to the number of projects completed to date.

Monitoring of demonstration projects is essential. Monitoring is a fundamental component of implementing stormwater management plans and facilities to evaluate how successfully the plan or facility is and whether changes are needed in operation, maintenance (procedures or frequency), or design to meet regulatory goals. The monitoring program is often unique to each BMP or demonstration site and must be designed in the context of the objectives of the program. For example, a monitoring program for a municipality seeking to comply with monitoring requirements under its NPDES permit might have relatively straightforward goals for certain pollutants of concern. However, also important is the more in-depth monitoring information gathered when determining factors affecting LID facility performance.

By monitoring demonstration projects for performance, results can be used to make predictions on the water quality and flow benefits gained by implementation compared to costs. This will help decision makers determine the most cost-efficient facility for various conditions that will have the most benefit to water quality and help meet regulatory requirements. In addition, the information gathered on technical performance of BMPs is expected to provide important input for simulation modeling of pollutant impacts associated with specific management scenarios in other locations or at a larger scale. Key principles of monitoring pilot projects include the following:

- Dedicate the time and resources to develop a sound monitoring plan. Complexities of plans will vary depending on monitoring objectives.
- Be sure to plan and budget for an adequate number of samples to enable proper data interpretation.
- Be aware of the many variables that need to be documented as part of a monitoring program.
- Be sure that the monitoring design properly identifies the relationship between storm characteristics and the design basis of the BMP and answers selected management questions.
- Properly implement and follow the monitoring plan, clearly documenting any adjustments to the program. Particularly important are proper equipment installation and calibration, proper sample collection techniques and analysis, and maintenance of equipment for longer term programs.
- Maintain data in an organized and well-documented manner, including monitoring data, BMP design and maintenance practices, and site characteristics.
- Clearly report study limitations and other caveats on using the data.

4.7 References

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5. LID Review Process

5.1 LID Review Process

Municipalities in the San Antonio River Basin generally follow a development review process that begins with submission of a plat or initial planning and zoning package. After initial approvals or coordination, civil engineers or contractors submit construction plans for review by agency staff or city engineers. Site clearing and grading may begin prior to final plan approval or immediately after receiving building permits from the city/county. Designing a site for LID practices either for new development or redevelopment requires a reorganized process from the typical project engineering approach. The site planning process presented in [Section 1.5](#) is iterative and requires input from a geotechnical engineer, landscape architect, civil engineer, and the building architect. Reviewers and developers or their engineers need to have a clear understanding of the stormwater management goals for the community and the best LID practices for a particular site to meet watershed-based targets. LID encourages adaptive land use such as minimizing impervious cover that often requires interpretation of paving, parking, and sidewalk ordinances. The process also lends itself to meeting with regulatory staff early in the process to agree upon and document analysis criteria and stormwater management goals that may vary from watershed to watershed and among land uses. Early coordination reduces interpretation of stormwater management approaches during the plan review stage and it can provide an opportunity for communities to offer expedited review to developers that implement LID to meet stormwater management goals.

Although most municipalities follow a similar plan review process, large cities require approvals from several departments while smaller towns may only have a few individuals involved. A general planning review process is presented in Figure 5-1 to highlight the traditional plan review process and present a potential LID alternative. Each municipality is encouraged to develop checklists or review flow charts that fit their ordinances and organizational structure.

The traditional stormwater management approach in the San Antonio River Basin has focused primarily on flow rates for extreme storm events (e.g., 5-year, 10-year, 50-year, 100-year). This approach is based on the long history of catastrophic floods that have occurred from hurricanes, severe thunderstorms and tropical storms. Peak flow rates are analyzed to prove No Adverse Impact, size infrastructure, and verify detention measures to mitigate increased runoff if required. The same analysis will be needed for LID-based site design. However, when analyzing smaller design storms, BMP siting, sensitive area preservation, soil definition, and natural topography influence stormwater management to a much greater degree. Chapter 1 includes background on overall stormwater management approaches and site planning that each regulator or reviewer can reference. Careful assessment of pre-project hydrology will be required to ensure LID BMPs mimic the volume and flow rate after development for the water quality design storm. In addition, construction envelopes will have to be verified during construction to preserve sensitive areas. Figure 5-2 outlines the traditional stormwater management review process along with a sample LID-based approach that can be used as an initial template. It is recommended that each municipality tailor this process to meet their adopted stormwater regulations based on input from, at a minimum, planning, engineering, environmental, maintenance, and landscaping departments.

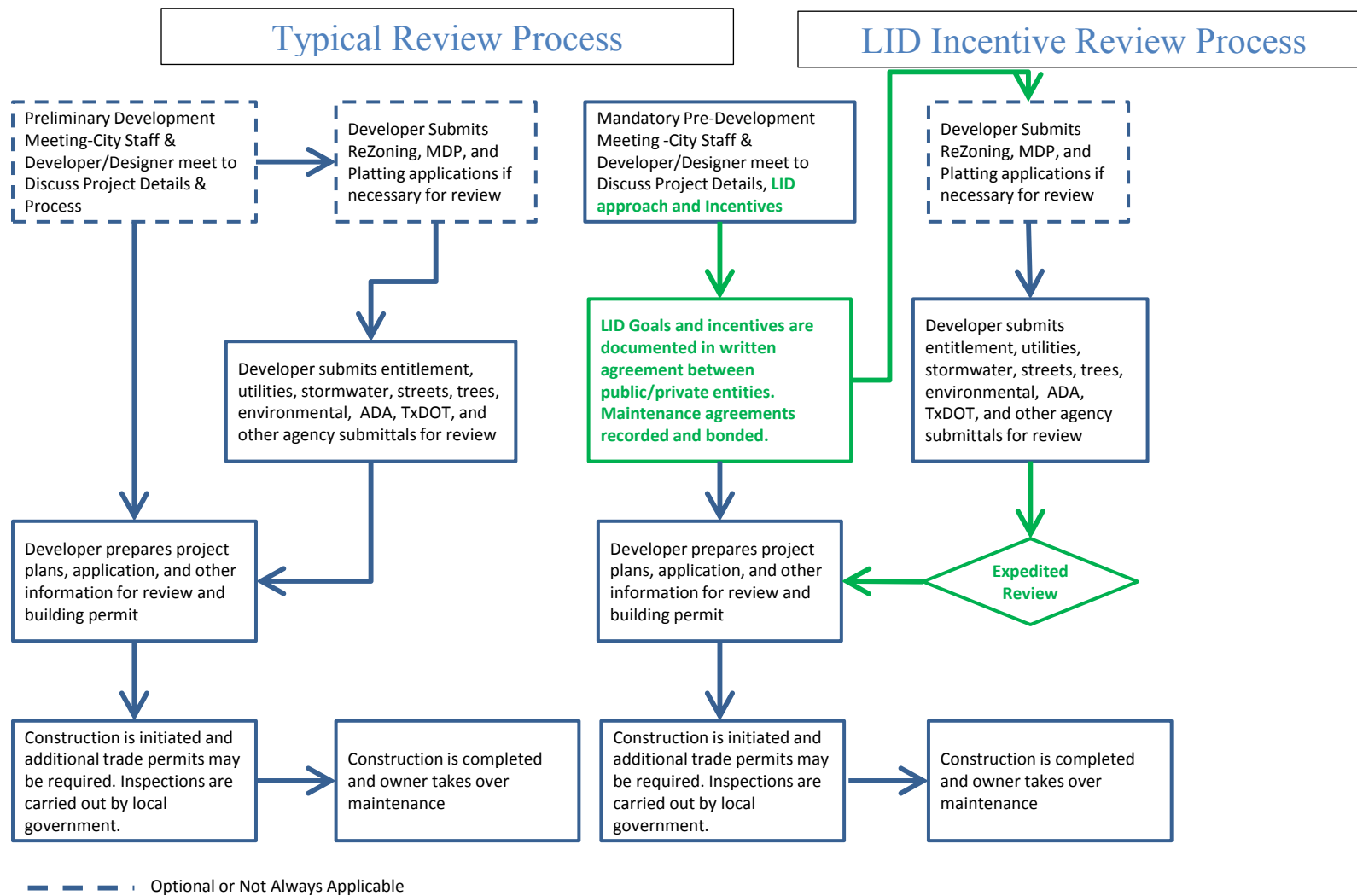


Figure 5-1. General planning review process

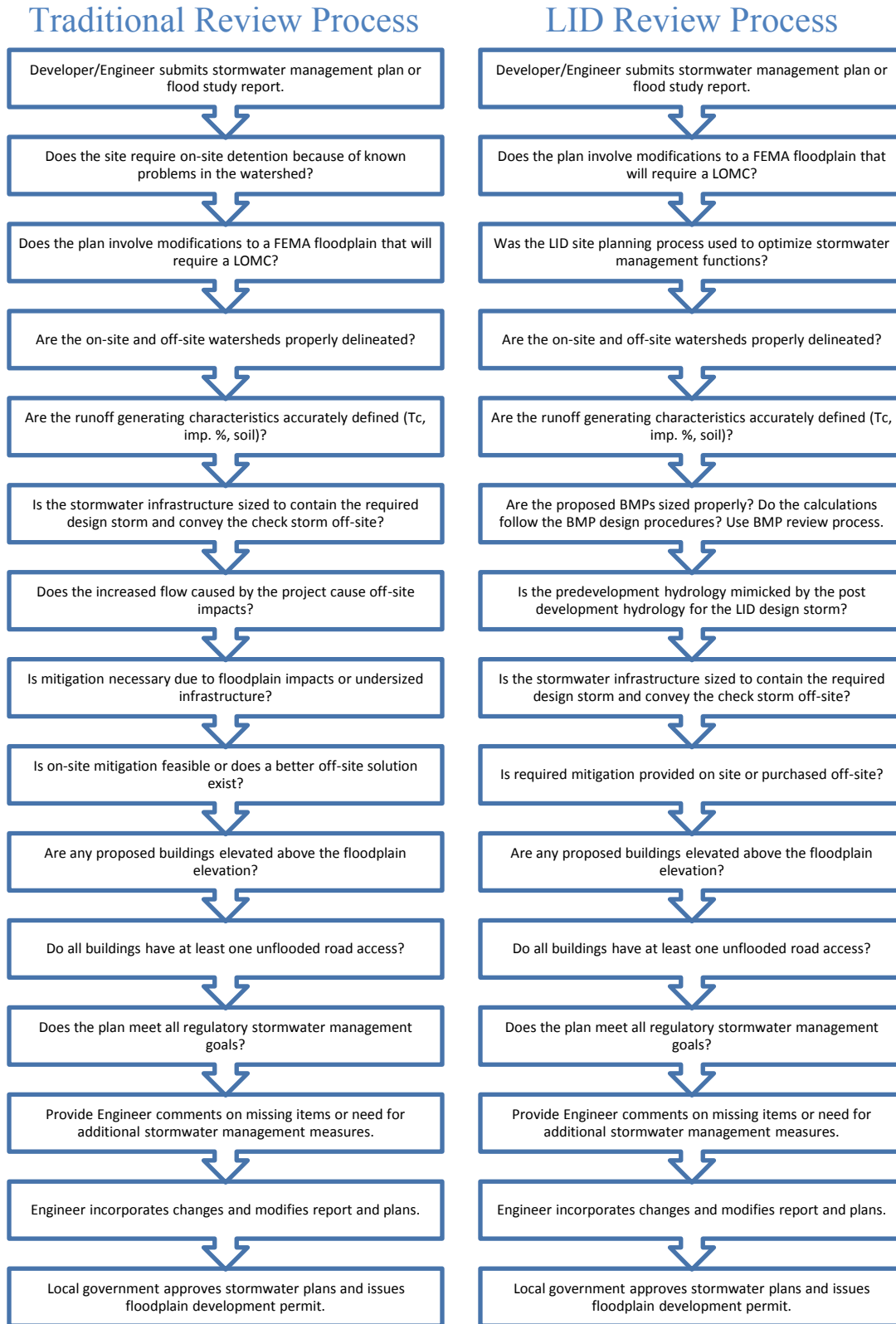


Figure 5-2. Traditional vs. LID design review process

Chapter 5: LID Review Process

The LID BMPs presented in [Chapter 3](#) necessarily provide the designer with flexibility to adapt to each site. The flexibility also presents more opportunity for unintended design consequences, especially where hydraulic controls are needed to meet water quality goals. Reviewers are encouraged to read the general information in [Chapter 3](#) and the detailed design steps in Appendix B prior to evaluating the individual BMPs proposed for a project or site plan. Armed with this knowledge, the reviewer can look for flaws that may not be apparent while assessing the typical components of each treatment process.

The BMPs share many elements that are presented in Appendix B - Common Design Elements, but a tailored process for each BMP type is helpful to guide the reviewer in the specific application. Figure 5-3 to Figure 5-12 below provide a template review process for each of the BMP types covered in this manual. They can be used separately or in series if multiple BMPs are used in a treatment train. Review agencies are encouraged to adapt the steps or format to their internal processes rather than rely exclusively on these diagrams. They are recommended for use as part of the overall site stormwater management review process rather than a stand-alone function. The flow charts are ordered to step through the design process while providing check points for assessing interaction with other site elements such as pavement and buildings. Vegetated filter strips and swales are included in the same flow chart because they use an almost identical design process. They also only provide filtering functions as pretreatment for other BMPs. Green roofs are usually the most complex BMP to design due to structural building considerations. Detailed technical references are provided in Appendix B for understanding the full design scope of their application.

Bioretention, bioswales, planter boxes, and sand filters are used in very similar ways throughout a site but apply to different drainage area sizes. The main differences occur in residence time and removal functions, which are described in Tables 3 and 4. Cisterns are primarily a volume capture and storage process, which initially seem straightforward to size and place on a site. The review flow chart focuses on the interaction with surrounding buildings where excess water can create maintenance and structural issues. Permeable pavement review is focused on siting and maintenance issues that can lead to clogging and long-term performance issues. Stormwater wetlands are the most marginal BMP choice in the San Antonio River Basin's semiarid climate due to permanent water needs. Wetlands should not require make-up water unless reuse water is available and no higher use (flushing, irrigation, etc.) is necessary.

Bioretention Review Process

- Is the watershed delineated correctly (<5 acres)?
- Are the runoff-generating characteristics accurately defined (T_c , imp. %, soil)?
- Is the treatment volume calculated correctly?
- Do the media storage capacity and ponding depth meet the required volume?
- Does the soil media meet the design guidance? If proprietary, is the claimed flow rate too high (< 30 in/hr)?
- Is the bioretention area properly sized and configured on the site plan?
- Will the BMP use infiltration? Is there technical data to support an adequate infiltration rate (>0.5 in/hr)?
- Does the inlet configuration assure flow capture? Is there enough head difference? Is the inlet big enough to resist plugging?
- Is the inlet transition designed to reduce erosion (cobble, drop basin)?
- Is a forebay or other pretreatment BMP provided to capture sediment?
- Is the BMP configured with an overflow or bypass? Is it sized correctly?
- If infiltrating BMP, are lateral flows restricted if necessary to prevent pavement or foundation damage?
- Are ancillary benefits (e.g., habitat, education, shade) maximized?
- Does the vegetation meet the aesthetic, seasonal, sun exposure, and maintenance needs of the site?
- Are there physical hazards to pedestrians, cyclists, or traffic with the design?

Figure 5-3. Review process for bioretention

Bioswale Review Process

- Is the contributing area delineated correctly? Bioswales typically treat small watersheds or one side of a roadway/parking lot.
- Are the runoff-generating characteristics accurately defined (Tc, imp. %, soil)?
- Is the treatment volume calculated correctly?
- Do the media storage capacity and ponding depth meet the required volume?
- Does the soil media meet the design guidance? Will it support plant growth and reduce inflow nutrient concentrations?
- Is the bioswale area properly sized and configured on the site plan?
- Will the BMP use infiltration? Does the underlying soil have an adequate infiltration rate (>0.5 in/hr)?
- Does the inlet configuration assure flow capture? Is there enough head difference to prevent ponding and flooding?
- Is the inlet transition designed to reduce erosion (filter strip, cobble, gravel splash pad)?
- Will velocity remain below 1 ft/s for mulched swales and below 3 ft/s for grassed swales?
- Is the BMP configured with an overflow or bypass? Is it sized correctly?
- If infiltrating design, are lateral flows restricted to prevent pavement or foundation damage?
- Is the underdrain sized properly? Will the bed drain completely if required?
- Are ancillary benefits (e.g., habitat, education, shade) maximized?
- Does the vegetation meet the aesthetic, seasonal, sun exposure, and maintenance needs of the site?
- Are there physical hazards to pedestrians, cyclists, or traffic with the design?

Figure 5-4. Review process for bioswales

Permeable Pavement Review Process

- Is the watershed draining to the BMP delineated correctly (1:1 ratio of watershed to BMP allowed with proper maintenance)?
- Are the runoff-generating characteristics accurately defined (T_c , imp. %)?
- Is the treatment volume calculated correctly?
- Do the aggregate base storage capacity and ponding depth meet the required storage volume? Have the structural requirements been verified by a geotechnical engineer?
- Is the BMP area sized correctly? Is the infiltration rate high enough to handle the peak rainfall or flow rate?
- Is the BMP used in pedestrian walkways, parking stalls, and low volume traffic areas and not used in loading or dumpster parking areas?
- Does the site grading divert water that may contain sediment or floatables away from the pavement?
- Are edge restraints provided for all discrete sections of pavement to prevent lateral shifting and edge unraveling?
- Will the BMP use infiltration? Does the underlying soil have an adequate infiltration rate (>0.5 in/hr)?
- If roof drainage is directed to the pavement, is the flow screened to remove leaves, trash and other materials that may clog the BMP?
- Is the BMP configured with an overflow or bypass? Is it sized correctly?
- If infiltrating, are lateral flows restricted if necessary to prevent pavement or foundation damage?
- Is the underdrain sized properly? Will the aggregate base drain completely if required?
- Are ancillary benefits (e.g., education, rainwater reuse, tree protection, detention) maximized?
- Is signage provided to prohibit activities that cause premature clogging and notify owners the pavement is intended to be permeable?
- Are there physical hazards to pedestrians, cyclists, or wheelchair users?

Figure 5-5. Review process for permeable pavement

Planter Box Review Process

- Is the contributing area delineated correctly? Planter boxes offer treatment for single downspouts or small impervious areas.
- Are the runoff generating characteristics accurately defined (T_c , imp. %)?
- Is the treatment volume calculated correctly?
- Do the media storage capacity and ponding depth meet the required volume?
- Is the ponding depth too deep? Could it overflow and flood a building?
- Does the soil media meet the design guidance? Is the claimed flow rate for proprietary media sufficient to treat flow?
- Will the media support plant growth and reduce inflow nutrient concentrations?
- Is the planter box properly sized and configured on the landscaping/site plan?
- Does the inlet configuration assure flow capture? Is there enough head difference to prevent bypass or unintended washout?
- Is the inlet transition designed to reduce erosion (cobble, gravel splash pad, concrete apron)?
- Is the BMP configured with an overflow or bypass? Is it sized correctly? Will it create ponding issues or backup the storm drain or downspout?
- Is the concrete box or hydraulic restriction layer sufficient to prevent damage to surrounding structures?
- Is the underdrain sized properly? Will the bed drain completely or to the internal water storage elevation?
- Are ancillary benefits (e.g., habitat, education, shade) maximized?
- Does the vegetation meet the aesthetic, seasonal, sun exposure, and maintenance needs of the site?
- Are there physical hazards to pedestrians, cyclists, or traffic with the design?

Figure 5-6. Review process for planter boxes

Green Roof Review Process

- Is the total roof area correctly delineated?
- Is the treatment volume reasonable based on media depth and area?
- Has a structural engineer calculated the roof loading?
- Is the roof extensive (< 6 in media) or intensive (> 6 in media)?
- Is the impermeable liner properly specified?
- Is the drainage layer included and separated from the soil media by a geotextile?
- Does the soil media meet the requirements for green roofs (well drained, high porosity, lightweight, permanent, stable, etc.)?
- Is the underdrain sized to convey the peak flow rate through the media?
- Is the underdrain routed safely off the building to a proper discharge point?
- Is the water quality volume drained to an irrigation or infiltration area?
- Is the BMP configured with an overflow or bypass? Is it sized correctly to convey the 100-year storm?
- Is the overflow or bypass water routed safely away from the building?
- Is the vegetation selected properly based on type of green roof? Extensive roofs are more limited.
- Is condensate or rainwater harvesting available to make up irrigation needs in summer?
- Are ancillary benefits (e.g., insulation, green space, water reuse) maximized?
- If green space for public access is intended, are proper safety measures in place to prevent falls?

Figure 5-7. Review process for green roofs

Sand Filter Review Process

- Is the watershed delineated correctly (<5 acres)?
- Are the runoff-generating characteristics accurately defined (Tc, imp. %, soil)?
- Is the treatment volume calculated correctly? Will the BMP bypass before overflowing or backing up into the site?
- Do the media storage capacity and ponding depth (<3 feet) meet the required volume?
- Is the sand filter properly sized and configured on the site plan? Is the surface area large enough?
- Does the sand media meet the design guidance? Is it at least 1.5 feet thick?
- Will the BMP use infiltration? Does the underlying soil have an adequate infiltration rate (>0.5 in/hr)?
- If infiltrating, are lateral flows restricted if necessary to prevent pavement or foundation damage?
- Does the inlet configuration assure flow capture? Is there enough head difference? Is the inlet big enough to resist plugging?
- Is the inlet transition designed to reduce erosion (cobble, drop basin)?
- Is a forebay, grass filter strip or vegetated swale provided as pretreatment?
- Is the BMP configured with an overflow or bypass? Is it sized correctly?
- Is the underdrain sized properly? Will the bed drain completely if required?
- Does the vegetation meet the aesthetic, seasonal, sun exposure, and maintenance needs of the site?
- Are ancillary benefits (e.g., recreation, education, detention) maximized?
- Are there physical hazards to pedestrians or site users?

Figure 5-8. Review process for sand filters

Stormwater Wetland Review Process

- Is the contributing area delineated correctly? Wetlands can treat watersheds greater than 5 acres.
- Are the runoff generating characteristics accurately defined (Tc, imp. %, soil)?
- Is the treatment volume calculated correctly? Add 20% to runoff volume for sediment accumulation.
- Is a water balance provided showing enough water for a permanent deep pool(s)?
- Wetlands require an impermeable liner or low permeability *in situ* soils. Has a geotechnical study of the pond site been performed?
- Is the wetland properly sized and configured on the site plan to collect drainage by gravity?
- Does the inlet configuration ensure flow capture? Is there enough head difference to provide conveyance into pond?
- Is the inlet designed to reduce erosion from large storms? Will hydraulic jump occur at outlet of collection system?
- Is the forebay sized to still the incoming flow, settle large particles and collect floatables?
- Is a berm or weir provided to dissipate flow into the main body of the wetland?
- Are the required four zones designed into the wetland? Is the flow length maximized?
- Is the BMP configured with an overflow or bypass? Is it sized correctly? Is an emergency spillway provided?
- Is a maintenance/emergency dewatering intake provided? Is it sized to drain the wetland in 24 hours?
- Does the soil media support establishment of native wetland plant species?
- Does the vegetation meet the criteria for wetland plants?
- Are the planting areas 3–6 inches deep to prevent undesirable plants?
- Are ancillary benefits (e.g., habitat, education, shade, park space) maximized?

Figure 5-9. Review process for stormwater wetlands

Cistern Review Process

- Is the roof area draining to the cistern identified correctly?
- Is the Time of Concentration correct?
- Is the treatment volume calculated correctly?
- Will the foundation support the weight of a full tank?
- Will the pipe from the roof to the cistern safely convey the 100-year flow?
- Is a self-cleaning inlet filter provided?
- Is a first flush diverter included and configured properly?
- Is the first flush volume routed to another BMP?
- Is the low flow outlet sized to drain the water quality volume from the tank within two days?
- Is the water quality volume drained to an irrigation or infiltration area?
- Is the BMP configured with an overflow or bypass? Is it sized correctly?
- Is the overflow or bypass water routed safely away from the building?
- Is signage stating “Caution: Reclaimed Water, Do Not Drink” provided?
- Are pipes conveying water painted Pantone color #512, and do valves have locking features?
- Are ancillary benefits (e.g., irrigation, toilet flushing, car washing) maximized?
- Are all inlets and outlets covered by 1-mm or smaller mesh to prevent mosquito entry?

Figure 5-10. Review process for cisterns

Extended Detention Basin Review Process

- Is the contributing area delineated correctly? Extended Detention Basins can treat watersheds greater than 5 acres.
- Are the runoff-generating characteristics accurately defined (Tc, imp. %, soil)?
- Is the treatment volume calculated correctly? Add 20% to runoff volume for sediment accumulation.
- Has a geotechnical study of the pond site been performed?
- Is the Extended Detention Basin properly sized and configured on the site plan to collect drainage by gravity?
- Are the forebays and micropool properly sized and configured on the site plan?
- Does the inlet configuration ensure flow capture? Is there enough head difference to provide conveyance into the micropool and outlet?
- Are the inlet and forebay designed to reduce erosion from large storms? Will hydraulic jump occur at outlet of collection system?
- Is the forebay sized to still the incoming flow, settle large particles and collect floatables?
- Is the flow length maximized to prevent short circuiting and maximize settling?
- Is the BMP configured with an overflow or bypass? Is it sized correctly? Is an emergency spillway provided?
- Is a trash rack including and properly designed?
- Is the basin and outlet sized to drain in 48 hours for the design storm?
- Does the soil media support establishment of native plant species? Are native plant species identified to attract pollinators?
- Are the planting areas at minimum 3–6 inches tall in order to prevent growth of undesirable plants?
- Are ancillary benefits (e.g., habitat, education, shade, park space) maximized?

Figure 5-11. Review process for extended detention basin

Vegetated Swale/Vegetated Filter Strip Review Process

- Is the contributing area delineated correctly (< 50 ft for VFS or <1 acres for VS)?
- Are the runoff-generating characteristics accurately defined (Tc, imp. %, soil)?
- Is the treatment flow rate calculated correctly?
- Does the site plan provide room for the VS or VFS? Does the siting fit the guidelines for VS or VFS placement to collect sheet flow or runoff from small on-site areas?
- Will the proposed configuration support vegetative cover sufficient to provide treatment? Check grass type, slope, soil depth (**min. 6 inches**), sun exposure, and water needs.
- Do the cross-sectional area, width and slope result in the calculated velocity?
- Does the calculated velocity provide for the recommended 10 minute detention time? Will velocity remain below 1 ft/s and depth below 1 inch for VFS?
- Can the VFS/VS convey higher design storm flow (5- to 25-yr) without excessive erosion or damage?
- Does the inlet configuration assure flow capture? Is there enough head difference? Is the inlet big enough to resist plugging?
- Will the curb inlet or grading configuration encourage sheet flow? Is a level spreader needed to prevent rill formation?
- Are swale side slopes greater than 3:1? Are internal check dams or trees included to maximize water retention? Can the tree species survive short periods of inundation?
- Will ponding or increased infiltration cause hazards or nuisance problems?

Figure 5-12. Review process for vegetated swales and vegetated filter strips

5.2 Incentives

A variety of incentives can be used by regulators to encourage LID implementation for new development and existing development. Incentives can encourage developers to use LID practices during the planning and design process for new development projects. For existing development, incentives can help property owners retrofit their sites with LID BMPs. According to the U.S. EPA, four common incentive mechanisms used at the local level are fee discounts or credits, development incentives, BMP installation subsidies, and awards and recognition programs, as described below (USEPA 2012):

1. Stormwater fee discount or credit

Municipalities often charge a stormwater fee based on the amount of impervious surface area on a property. If a property owner decreases a site's imperviousness or adds LID practices to reduce the amount of stormwater runoff that leaves the property, the municipality will reduce the stormwater fee or provide a credit that helps the landowner meet a water quality performance or design requirement.

2. Development incentives

Local governments can offer incentives that are only available to a developer who uses LID practices. Some economic development corporations will use these incentives to encourage development on targeted sites, such as redevelopment in downtown or underserved areas. For example, cities might offer to waive or reduce permit fees, expedite the permit process, allow higher density developments, or provide exemptions from local stormwater permitting requirements for developers that use LID practices to meet stormwater management goals.

3. Rebates and installation financing

To offset costs, cities might offer grants, matching funds, low-interest loans, tax credits or reimbursements to property owners who install specific LID practices or systems. For example, some communities offer programs that subsidize the cost of rain barrels, plants, and other materials that can be used to control stormwater. Similarly, public improvements financed through public/private partnerships can require LID implementation to meet community goals.

Local Incentives for Green Infrastructure

Fee discounts or credits require a stormwater fee that is based on impervious surface area. If property owners can reduce need for service by reducing impervious area, the municipality reduces the fee.

Development incentives are offered to developers during the process of applying for development permits. They include zoning upgrades, expedited permitting, reduced stormwater requirements, and other incentives.

Rebates and installation financing give funding, tax credits or reimbursements to property owners who install specific practices. These incentives are often focused on practices needed in certain areas or neighborhoods.

Awards and recognition programs provide marketing opportunities and public outreach for exemplary projects. These programs may include monetary awards.

Source: USEPA 2010

4. Awards and recognition programs

More communities are holding LID-design contests to encourage local participation and innovation. Many communities highlight successful LID sites by featuring them in newspaper articles, on websites and in utility bill mailings. Some also issue yard signs to recognize property owners who have installed LID. Recognition programs can help to increase property values, promote property sales and rentals, and generally increase demand for the properties. Businesses receiving green awards can enhance sales materials to generate increase revenue.

Resources

Green Infrastructure Case Studies: Municipal Policies for Managing Stormwater with Green Infrastructure

In 2010, EPA developed a report presenting common trends among 12 local governments that developed and implemented stormwater policies to support green infrastructure. Stormwater fee discounts and other incentives are discussed in detail, including a framework for stormwater fee discount programs. The report can be found at http://www.epa.gov/owow/NPS/lid/gi_case_studies_2010.pdf.

Managing Wet Weather with Green Infrastructure Municipal Handbook Incentive Mechanisms

EPA's Municipal Handbook provides local governments with a step-by-step guide to growing green infrastructure in their communities. The Incentive Mechanisms chapter describes a number of incentives that municipalities can offer to promote the implementation of green infrastructure on private properties and reduce their stormwater management costs. The guide can be found at http://water.epa.gov/infrastructure/greeninfrastructure/upload/gi_munichandbook_incentives.pdf.

Green Infrastructure Funding and Incentives Webcast

In 2009 EPA held a webcast on green infrastructure funding and incentives, which can be viewed at http://cfpub.epa.gov/npdes/courseinfo.cfm?program_id=0&outreach_id=460&schedule_id=1059.

5.3 Stormwater Fee-in-Lieu Programs

Traditional programs for stormwater management have allowed participation in regional programs that fund municipally owned detention basins, conveyance channels, and large underground storm drainage systems. This approach has been preferred by municipalities for maintenance reasons, to provide funding to fix existing flooding issues, and in some cases as a means to create public open space with water features that provide aesthetic benefits. Traditional programs usually focus on rare flood events such as the 10-year or 100-year event that, while damaging, occur infrequently.

LID approaches typically use distributed small-scale BMPs throughout a site to manage stormwater from frequent storms close to the impervious surfaces that create increased runoff. This on-site stormwater management is necessary due to excessive costs that would be required to meet water quality goals with end-of-pipe solutions in a typical development scenario. With redevelopment, there is often minimal open space near streams to fit large regional stormwater management practices.

On-site stormwater management programs incorporating LID tend to limit payment of fees in lieu of on-site stormwater mitigation (referred to as fee-in-lieu-of or FILO). These programs often allow

purchasing off-site credits from private retention credit banks. Regulatory agencies may choose to require a minimum on-site treatment (for example 50% of required water quality volume) for very small storms in the range of one half inch or less. Similar programs exist locally for tree mitigation where a land owner may choose to protect additional trees on a site and sell the credits to other developers. Stormwater management requires a watershed-based approach to credit programs so that volume reduction and treatment required to meet integrated stormwater management goals occurs upstream of monitoring points or regulated discharges. To date, most programs have been implemented as part of stormwater utilities or MS4 permit compliance measures and work in concert with stormwater fees assessed monthly based on either flat rates for residential properties or rates based on the amount of impervious cover on a site.

There are many opportunities to develop a comprehensive fee structure for stormwater management that blends flood control and LID outcomes. Non-structural LID approaches reduce impervious cover, preserve vegetation and protect high infiltration soils that can be exploited for increased treatment. This reduces overall stormwater impacts, which results in lower impact fees. Structural LID BMPs reduce runoff volumes and increase interception at the onset of all storms, which preserves detention volume for flood peaks. Many BMPs can also be oversized to temporarily detain flood volumes, which reduces storm drainage infrastructure costs. Integrated approaches may use varying requirements for design storms based on water quality and flood control needs. An example approach is presented in Table 5-1 below.

Table 5-1. Sample management approach blending water quality and flood control

Storm Size	Water Quality Management	Volume Management	Flow Rate Management	Conveyance Management
90 th percentile annual storm	✓	✓	✓	✓
2- to 25-year storms			✓	✓
100-year storm				✓

A site that fully implements LID with on-site detention can reduce or eliminate monthly stormwater fees and offset or eliminate flood control impact fees.

5.4 References

- USEPA (U.S. Environmental Protection Agency). 2010. Green Infrastructure Case Studies: Municipal Policies for Managing Stormwater with Green Infrastructure. http://www.epa.gov/owow/NPS/lid/gi_case_studies_2010.pdf. Accessed March 4, 2013.
- USEPA (U.S. Environmental Protection Agency). 2012. Encouraging Low Impact Development: Incentives Can Encourage Adoption of LID Practices in Your Community. http://www.epa.gov/owow/NPS/lid/gi_case_studies_2010.pdf. Accessed March 4, 2013.

Glossary

Absorption – The uptake of molecules of one substance directly into another substance.

Abstraction – Storage of precipitation on leaves, stems, organic litter, and shallow depressions on the land surface. The total storage is unavailable for runoff in hydrologic modeling of storm events.

Adsorption – The adhesion of atoms, ions, or molecules from a gas, liquid, or dissolved solid to a surface.

Alkalinity – The capacity of water for neutralizing an acid solution.

Area of concern – Areas where infiltration should be limited, such as sensitive groundwater areas or areas prone to sinkholes.

Artesian zone (Edwards Aquifer) – The downstream-most zone located directly above the confined Edwards Aquifer. Recharge is limited by relatively impermeable layers overlying the Edwards Aquifer and positive hydraulic pressure of the confined aquifer.

As-built – Drawings prepared by the construction contractor showing changes to the construction plans or recording final dimensions or elevations.

Base flow – The portion of stream flow that occurs during fair weather and is contributed by groundwater sources such as interflow or spring flow.

Best management practices (BMPs) – Nonpoint Source BMPs are specific practices or activities used to reduce or control impacts to water bodies from nonpoint sources, most commonly by reducing the loading of pollutants from such sources into storm water and waterways. (TCEQ)

Bioaccumulation – The accumulation of substances, such as pesticides, or other organic chemicals in an organism.

Biofiltration – The process of removing contaminants from stormwater using biological processes of plants, microorganisms, and organic matter.

Biological integrity – The ability of an ecosystem to support and maintain a balanced, integrated, and adaptive community of organisms having a species composition, diversity, and functional organization comparable to the best natural habitats within a region.

Bioretention (rain gardens) – A stormwater management technique that typically uses parking lot islands, planting strips, or swales to collect and filter urban stormwater. The cells include grass and sand filters, loamy soils, mulch, shallow ponding and native trees and shrubs.

Biotransformation – The chemical modification (or modifications) made by an organism on a chemical compound.

Chicanes – A horizontal diversion of vehicular traffic designed to reduce speed and increase safety for pedestrians, bicyclists and motorists.

Coagulation – A joining together of particles that settle out in waste water. Lime, alum, and iron salts induce the clumping of particles.

Complete street – Streets designed and operated to enable safe access and travel for all users. Pedestrians, bicyclists, motorists, transit users, and travelers of all ages and abilities will be able to move along the street network safely.

Contributing zone (Edwards Aquifer) – Located on the Edwards Plateau, the contributing zone is the upstream-most zone of the Edwards Aquifer drainage area. Rainfall infiltrates to recharge the water table aquifer or runs off overland to the recharge zone.

Conveyance systems – Stormwater management systems designed to efficiently convey runoff from a site or watershed into a receiving stream. Systems are typically comprised of impervious segments such as driveways, streets, closed pipes, lined channels and engineered earthen channels.

Curb cuts – An opening formed or cut into curbs to allow runoff collected in the street to enter a surface stormwater management feature.

Curbs A concrete barrier on the margin of a road or street that is used to direct stormwater runoff to an inlet, protect pavement edges, and protect lawns and sidewalks from encroachment by vehicles.

Depression storage – The amount of rainfall stored on the surface of the ground in small depressions or puddles. This storage reduces initial storm runoff and the water is lost to evaporation, transpiration, or infiltration.

Detention – A stormwater management approach that temporarily holds back water and releases it at a rate slower than the maximum inflow rate. Detention is not typically design to reduce the total volume of runoff.

Development envelope – The limit of disturbance that will meet the site development plan while causing the smallest hydrologic impact

Drip line – A ring around the tree canopy on the ground level that receives most of the rainwater shed from the tree canopy. Feeder root locations go beyond the drip line to get moisture and nutrients being created from organic matter in and on top of the soil.

Easements – An easement is defined as a right, privilege or advantage in real property, existing distinct from the ownership of the land. Most commonly, an easement entails the right of a person (or the public) to use the land of another in a certain manner such as electric, cable, drainage, gas and water easements.

Ecological impairments – an impact resulting from pollutant loading, channel degradation, increased flow, and loss of habitat structure that reduces the livability or long term health of aquatic habitat.

Emergent vegetation – Herbaceous wetland plants that root in shallow water and extend above the water surface.

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Ephemeral stream – A stream or waterway that holds water only for a few hours or days, and dries up shortly after rain storms.

Erosion – The wearing away of land surface by wind or water. Erosion occurs naturally from weather or runoff but can be intensified by increased runoff and land-clearing practices related to farming, residential or industrial development, road, building, or timber cutting.

Evapotranspiration – The combined loss of water from a given area, and during a specified period of time, by evaporation from the soil surface and transpiration from plants into the atmosphere.

Exfiltration – The seepage of water into the native subsoil beneath a stormwater infiltration BMP.

Floatables – Any foreign matter that may float or remain suspended in the water column and includes plastic, aluminum cans, wood products, bottles, and paper products.

Flocculation – The process by which suspended colloidal or very fine particles are assembled into larger masses or floccules that eventually settle out of suspension.

Green Infrastructure (GI) – Sustainable pollution reduction practices that also provide ecosystem services. GI includes both preserved natural areas and man-made BMPs.

Ground water – Water stored underground that fills the spaces between soil particles or rock fractures. A zone underground with enough water to withdraw and use for drinking water or other purposes is called an aquifer.

Horizontal deflectors – See **chicanes**.

Hotspot (Stormwater Hotspot) – Areas where infiltration into native soils should be restricted due to risk of contamination. Areas include, but are not limited to: fueling stations, vehicle/equipment maintenance and wash facilities, solid waste facilities, and trucking/railroad facilities.

Hydrologic cycle – The natural cycle of water on earth, including precipitation as rain and snow, runoff from land, storage in lakes, streams, and oceans, and evaporation and transpiration (from plants) into the atmosphere.

Hydrologic flow path – The path that water follows across the ground, through the soil, or in groundwater.

Hydroperiod – The seasonal pattern of water levels in a wetland including periods of filling, draining, and dry periods. Wetland plants and animals are affected by changing hydroperiods caused by increased runoff.

Impervious cover – Any surface which cannot be effectively (easily) penetrated by water. Examples include conventional pavements, buildings, highly compacted soils, and rock outcrops.

Infiltration – The downward entry of water into the surface of the soil, as contrasted with percolation which is movement of water through soil layers.

Interception – The capture and storage of water on leaves, grass and buildings that are above the ground surface.

Interflow – Movement of water laterally through the unsaturated soil zone from a high topographic point to an outlet in a stream prior to becoming groundwater.

Intersection pop-outs – A form of bioretention used at intersections in the space that is the continuation of on street parking lanes. The space is typically signed or striped no parking to preserve sight distances.

Karst – A landscape formed from the dissolution of soluble rocks including limestone, dolomite and gypsum. It is characterized by sinkholes, caves, and underground drainage systems.

LID practitioner – People who are involved in the design, maintenance, monitoring and performance of LID.

LID strategies – Approaches to land development that are applied at the regional or watershed scale to protect undisturbed natural lands, cultural resources, and ecological value while encouraging efficient land use. Strategies can take the form of riparian, habitat, or sensitive area protection.

Low impact development – A stormwater management and land development strategy that emphasizes conservation and the use of on-site natural features integrated with engineered, small-scale hydrologic controls to more closely reflect pre-development hydrologic functions.

Manway – A hatch or port providing access to a cistern.

Mass loading – The total load of a pollutant that enters a receiving water over a specified unit of time. The mass load is found by multiplying the flow rate by the pollutant concentration over the time period.

Non-Point Source (NPS) Pollution - Nonpoint source pollution generally results from land runoff, precipitation, atmospheric deposition, drainage, seepage or hydrologic modification. NPS pollution is caused by rainfall or snowmelt moving over and through the ground. As the runoff moves, it picks up and carries away natural and human-made pollutants, finally depositing them into lakes, rivers, wetlands, coastal waters and ground waters.

Peak flow control – A stormwater management approach that focuses on limiting peak flow during design storms (water quality, flood control or combination) to a target usually set by existing or pre-development conditions.

Percolation – The downward movement of water through soil layers, as contrasted with infiltration which is the entry of water into the surface of the soil.

Photolysis – The breakdown of a material by sunlight; an important mechanism for the degradation of contaminants in air, surface water, and the terrestrial environment.

Phytoremediation – The direct use of green plants and their associated microorganisms to stabilize or reduce contamination in soils, sludges, sediments, surface water, or ground water.

Precipitation – A method of causing contaminants that are either dissolved or suspended in solution to settle out of solution as a solid precipitate, which can then be filtered or otherwise separated from the liquid portion. Chemical precipitation is a widely used, proven technology for the removal of

Glossary

metals and other inorganics, suspended solids, fats, oils, greases, and some other organic substances from wastewater, drinking water, and occasionally in wastewater.

Pre-development – The description of land cover, soil profile, hydrologic characteristics and water movement within a site or study area that would exist without human disturbance.

Recharge – Infiltration of surface water to groundwater.

Recharge zone (Edwards Aquifer) – The recharge zone is directly downstream from the contributing zone and consists of highly fractured limestone. Rainfall and runoff directly recharge the confined Edwards Aquifer through deep networks of fissures, faults, and sinkholes.

Reduction-oxidation (redox) potential – A chemical reaction consisting of an oxidation reaction in which a substance loses or donates electrons, and a reduction reaction in which a substance gains or accepts electrons. Redox reactions are always coupled because free electrons cannot exist in solution and electrons must be conserved.

Retention – A stormwater management technique that captures water permanently and reduces volume and flow rate. The captured water is reused for irrigation or allowed to naturally infiltrate and evapotranspire.

Right-of-way – Right of way is a general term denoting land, property or interest therein, usually in a strip, acquired for or devoted to a highway for the construction of the roadway. Right of way is the entire width of land between the public boundaries or property lines of a highway.

Runoff coefficient – The runoff coefficient is based on permeability and determines the portion of rainfall that will run off the watershed. The runoff coefficient value, expressed as C, can vary from close to zero to up to 1.0. A low C value indicates that most of the water is retained for a time on the site, as by soaking into the ground or forming puddles, whereas a high C value means that most of the rain runs off.

Screeding – Leveling the surface of poured materials (such as pervious concrete or aggregate) using a flat board, beam, or plate.

Sensitive Cultural Areas – Areas with significant cultural value that require protection. Areas include ceremonial structures, cemeteries, large trees, artifact sites and locations of significant historical events.

Sensitive Natural Areas – Natural areas requiring protection of native landscape, plant life, wildlife, or ecological values. The areas include recharge features, endangered species habitat, steep slopes and riparian buffers.

Setbacks – A zone designated to protect sensitive areas from negative impacts associated with development.

Short circuit – A situation in which polluted runoff bypasses a stormwater treatment facility.

Site fingerprinting – A site design technique that minimizes disturbance during construction by defining the limits of clearing, soil compaction, material storage, and underground facilities.

Smart growth – A set of development principles to improve community livability, including mixing land uses, creating a range of housing types, preserving green space, creating compact and walkable development with a variety of transportation options, and focusing new development in or near areas of existing development.

Soil compaction – The process where soil particles are pressed together, reducing pore space between them. Compacted soils typically contain few large pores and have a reduced rate of both water infiltration and drainage from the compacted layer. Soil compaction is a result of equipment, vehicle and pedestrian traffic.

Stream morphology – The form and structures of streams that can be assessed to determine the stability, progression and health of streams.

Sustainable – A method, practice or approach that creates and maintains the conditions under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic and other requirements of present and future generations.

Time of concentration – The time required for runoff to travel from the hydraulically most distant point in the watershed to the outlet.

Total maximum daily loads (TMDLs) – The sum of the individual wasteload allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources and natural background, and a margin of safety (MOS). TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard.

Transition zone (Edwards Aquifer) – Located between the recharge zone and the artesian zone, this area features both deep infiltration and artesian springs.

Treatment train – A stormwater technique in which several treatment types (filtration, infiltration, retention, evaporation) are used in conjunction with one another and are integrated into a comprehensive runoff management system.

Urbanization – Urbanization refers to the concentration of human populations into discrete areas, leading to transformation of land for residential, commercial, industrial and transportation purposes. It can include densely populated centers, as well as their adjacent peri-urban or suburban fringes (EPA).

Walkability – The ease with which pedestrians can access businesses, schools, and facilities, in terms of distance and safety.

Zoning – A set of regulations and requirements which govern the use, placement, spacing, and size of land and buildings within a specific area (zone). Zoning regulations serve to promote the public health, safety, morals, or general welfare and to protect and preserve places and areas of historical, cultural, or architectural importance and significance.

Appendix A. BMP Sizing

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A.1 Introduction

Stormwater management techniques incorporating LID BMPs are focused on frequent smaller storm events typically in the range of one to two inches over 24 hours. Many jurisdictions provide either a volume target based on a storm depth or a flow rate target based on annual storm intensity. Permitting agencies in the San Antonio River Basin are encouraged to develop their own criteria based on national, state, and local guidance. Regulators or designers can perform localized BMP modeling to better define stormwater management goals or outcomes for a particular site. Refer to section A.2 for discussion on BMP modeling software. Alternatively, regulators could allow designers to use either of the following design criteria:

- **Volume-based control practices:** infiltrate, filter, or treat the volume of runoff necessary to meet a treatment target based on either the volume necessary to meet a specific annual pollutant reduction or the volume of runoff produced by a design storm (85th to 95th percentile storm event dependent on the city or county guidance).
- or
- **Flow-based control practices:** infiltrate, filter, or treat the maximum flow rate from the design intensity (typically exceeds 2.0 inches per hour) or *twice* the maximum flow rate from the design storm hourly rainfall intensity (typically 0.5 to 1.1 inch per hour intensity depending on the city or county guidance).

In fundamental terms, these design guidelines present sizing methodologies that ensure management of frequent small events with low to medium rainfall intensities while bypassing runoff from typical flooding events. The result is that a large portion of total annual runoff (i.e., runoff from the majority of storms that are smaller than the 90th percentile event) is managed by the BMP without the significant expense of oversized BMPs necessary to capture a 5-year to 100-year storm. These methods are summarized briefly below.

A.2 Stormwater Management Methods

Selecting the proper BMP type and location depends on site-specific precipitation patterns, soil characteristics, slopes, and existing utilities.

A.2.1 Volume Management

Volume management is typically required for offsetting hydromodification effects and to extend treatment times in BMP's for nutrient, metals, and temperature management. There are currently (2013) no statewide or San Antonio River Basin specific mandates for runoff volume management. However, the following methods to size BMPs for infiltrating, filtering, or treating stormwater to meet volume criteria are appropriate:

1. A hydrologic evaluation performed using continuous simulation hydrologic modeling and analysis techniques to determine the required treatment to meet multiple pollutant reduction and treatment goals. BMP performance curves for determining the rainfall depth that must be treated for a variety of pollutant reduction targets are presented in [Section A.3](#) of this Appendix.

or

2. The volume of runoff produced from a percentile storm event required by local regulations or encouraged through incentives. [Note: applicants may calculate the regulatory percentile storm event using local rain data, when available.]

or

3. The volume of annual runoff based on unit basin storage volume, to achieve 90 percent or more volume treatment by the method recommended in the latest edition of *Complying with the Edwards Aquifer Rules—Technical Guidance on Best Management Practices* (TGM) (TCEQ 2005). Please note that the TCEQ criteria do support the use of LID BMPs and treatment trains can be used to meet TSS reduction requirements and volume management.

For each of the methods presented above, a rainfall or precipitation depth will be determined. The water quality or treatment volume necessary to meet the treatment goals will be determined using the rainfall depth and the methods presented in [Section A.4](#).

A.2.2 Flow Management

Flow based designs are typically used for configuring inlets, sizing conveyance, or setting hydraulic controls. Flow based BMP's such as vegetative filter strips, high rate filter media, and grass swales can be used as part of a treatment train to meet LID criteria. Flow based methods are presented in [Section A.5](#).

A.3 BMP Performance Curves

Process-based continuous simulation models were used to generate the BMP performance curves. The watershed runoff response was simulated using the Hydrologic Simulation Program in FORTRAN (HSPF), while BMP responses were simulated using the System for Urban Stormwater Analysis and Integration (SUSTAIN). Both HSPF and SUSTAIN estimate runoff volume and pollutant fate and transport at a high temporal resolution (i.e. hourly or sub-hourly). Although not used in this analysis, another model commonly used for rainfall/runoff and storage/transport simulation is the StormWater Management Model (SWMM). One advantage of continuous simulation is its ability to show varied storm responses as a function of antecedent conditions. For example, a storm occurring in the spring immediately after another rainfall event will have a notably different response than an isolated storm of the same size occurring in the summer. Not only would runoff and pollutant loads differ, but also BMP performance would differ. The modeling approach used to generate the BMP performance curves considers all of those interactions when estimating BMP performance. In fact, it is the aggregations of those interactions that make BMP performance vary in a non-linear way as a function of BMP size.

Runoff hydrograph and pollutograph boundary conditions for the BMP performance curves presented here were generated using the HSPF models provided to Tetra Tech by SARA. The two major drainage basins represented by these models were Salado Creek and the Upper San Antonio River in Bexar County, Texas. The impervious land (IMPLND) blocks from those existing HSPF models served as the basis for generating runoff boundary conditions as input to SUSTAIN. The IMPLND block produces runoff volume and associated pollutant loadings, which represent BMP inflow for SUSTAIN. Figure A-1 is a schematic illustrating the various HSPF and SUSTAIN processes as well as the linkage between the two models.

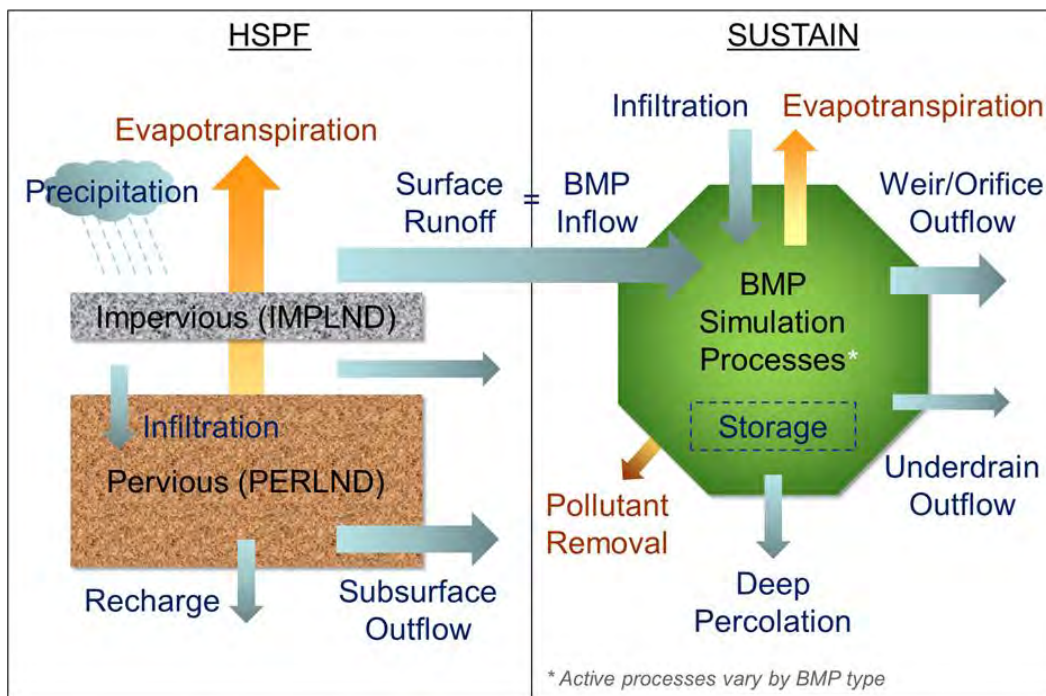


Figure A-1. Schematic of simulated HSPF and SUSTAIN processes and surface runoff linkage.

Appendix A.3 BMP Performance Curves

Model evaluation revealed that there were two unique groups of IMPLND runoff boundary conditions represented in the HSPF models, as summarized in Table A-1. Meteorological data from Station #12921 in the HSPF Watershed Data Management (WDM) file for calendar year 2007 were used to generate runoff hydrographs and pollutographs. That selected rainfall gage (12921) was evaluated against long-term National Climatic Data Center (NCDC) observed rainfall at San Antonio International Airport, as summarized in Table A-2. Among calendar years-in-common, 2007 was selected for this analysis because it had both the highest annual precipitation volume and the highest number of days with rainfall than any other year available in the HSPF WDM file.

Table A-1. Summary of land use types from the Salado and USAR HSPF models.

Land use group	Land use type	HSPF classification
Residential	Dispersed	Residential dispersed
	Low	Residential low
	Medium	Residential medium
	High	Residential high
	Multi-Family	Residential multi-family
Other urban	Commercial	Commercial
	Industrial	Industrial
		Services mixed-use
		Services utilities
	Transportation	Transportation
Open Space	Open space easements	
Water	Water (not considered here)	Water

Appendix A.3 BMP Performance Curves

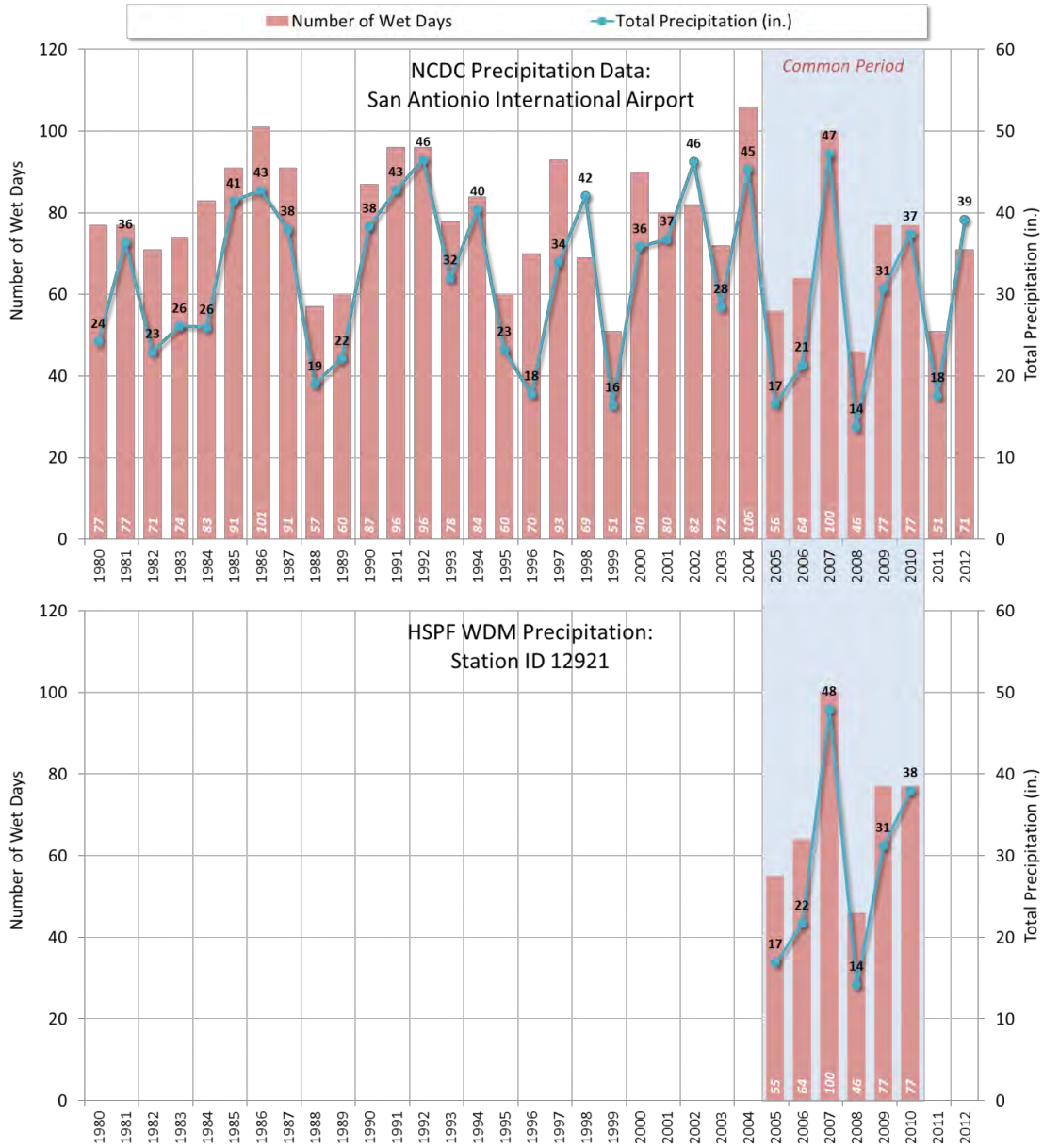


Figure A-2. Comparison of WDM precipitation at 12921 with corresponding NCDC long-term observed precipitation data.

Input parameters for the SUSTAIN model runs for all BMPs are available from the San Antonio River Authority upon request. BMPs were modeled for a range of site conditions, defined by hydrologic soil groups A, B, C, and D. An underdrain option was available for certain BMP types, as outlined in Table A-2 below. As shown in Table A-2, eight responses were modeled for every type of BMP. For bacteria, two different responses were modeled because the HSPF runoff loads from non-residential land use types were 50 percent lower than those from residential (as shown in Figure A-3 below). With the exception of *Open Space Easements* and *Water*, which are not relevant for runoff inputs for this BMP analysis, all other modeled HSPF boundary condition outputs were identical for all land use types.

Table A-2. Matrix of BMP model responses by site condition and BMP type.

Site conditions	BMP types	Model responses
A & B soils, no underdrain option	Bioretention basin	1) Flow volume 2) Bacteria a) Residential b) Com/Ind/Trans 3) CBOD 4) Sediment 5) Total-N 6) Total-P 7) Total-Pb 8) Total-Zn
A & B soils, with underdrain option	Bioswale	
C & D soils, with underdrain option	Permeable pavement	
A, B, C, and D soils (underdrain option is not applicable)	Stormwater wetland	
	Vegetated filter strip (VFS)	
Site-specific BMPs (native soil type is not applicable)	Cistern	
	Green roof	
	Planter box	
	Rain barrel	
	Sand filter	

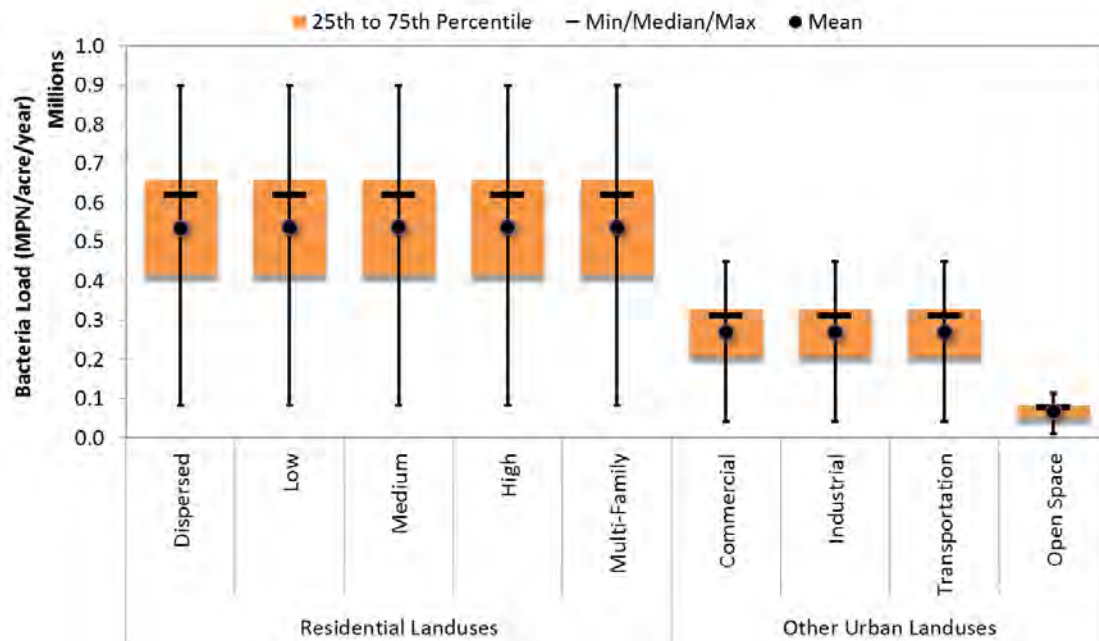


Figure A-3. HSPF modeled annual average bacteria export by impervious land use category.

For each of the unique modeled responses, there are six graphs: (1) bioretention basin, (2) bioswale, (3) permeable pavement, (4) stormwater wetland, (5) VFS, and (6) other site-specific BMPs. Each graph has multiple curves corresponding to the various applicable site conditions. There is only one graph for each of the five site-specific BMP types since they do not depend on the infiltration rate of the native soil. The last graph of each set of modeled responses presents results for all five site-specific BMP types. As previously noted, there are two different sets of modeled responses for bacteria because of land use differences in the HSPF boundary condition (i.e., *Residential* and *Commercial/Industrial/Transportation*).

Figure A-4 presents example performance curves showing flow volume reduction as a function of bioretention basin size. Annual percent reduction is for the modeled calendar year 2007. The x-axis represents BMP size and is interpreted as the equivalent *runoff* depth or rainfall depth captured

Appendix A.3 BMP Performance Curves

from one acre of impervious area. This depth is equal to the rainfall depth if one assumes that flow abstractions along the impervious surface upstream of the BMP are negligible. Figure A-4 presents two examples for how to use the curves to assist in BMP designs. The curves can be used either to estimate the benefit of sizing a BMP to a given size or to estimate the required size to achieve a desired level of performance. The first example (1 → 2 → 3) is for a bioretention basin with underdrain to be built in an area with native C-soils. For this example, the light-blue curve is used. If the BMP is being sized to capture 1.5 inches of runoff, equivalent to a rainfall depth of 1.5 inches, it is expected to reduce annual average runoff by 50 percent (for selected the 2007 wet year). The second example (4 → 5 → 6) is for a BMP to be built in an area with native B-soils, with no underdrain. For this example, the green curve is used. This time, the desire is to control 75 percent of annual runoff (for 2007); therefore, the BMP must be sized to capture 2.2 inches of runoff, equivalent to a rain fall depth of 2.2 inches. The runoff or rainfall depths determined in the performance curves below is then applied to the methods presented in [Section A.4.1](#) to determine the water quality volume.

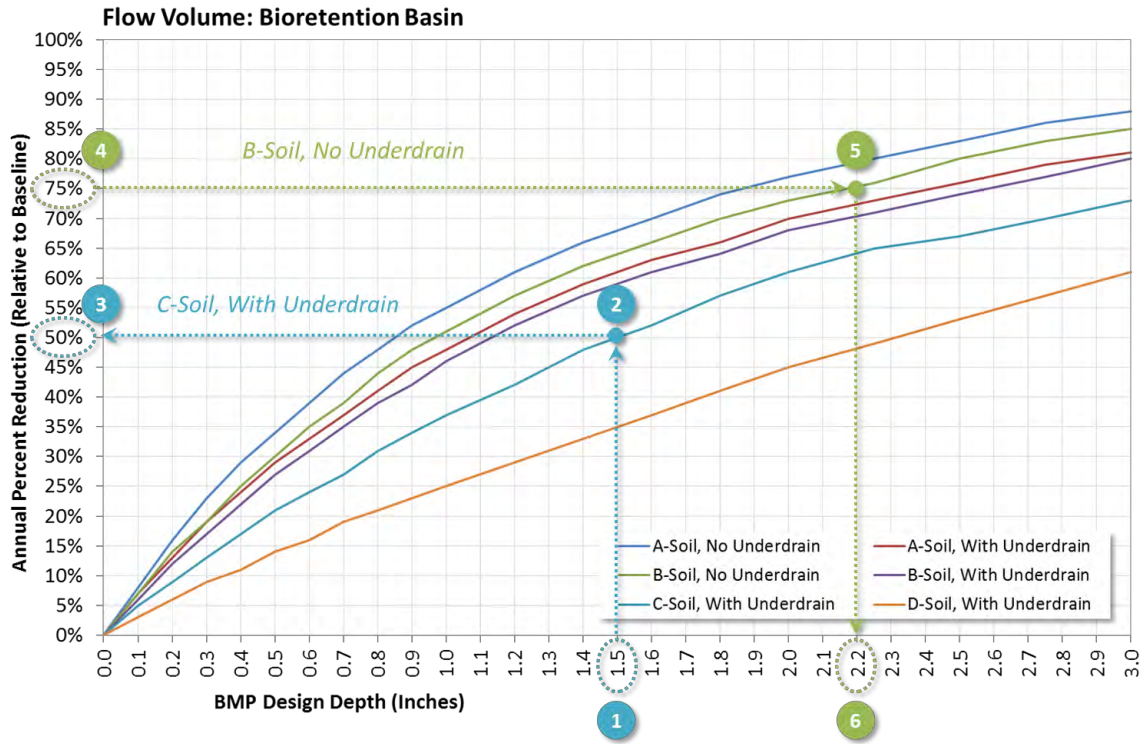
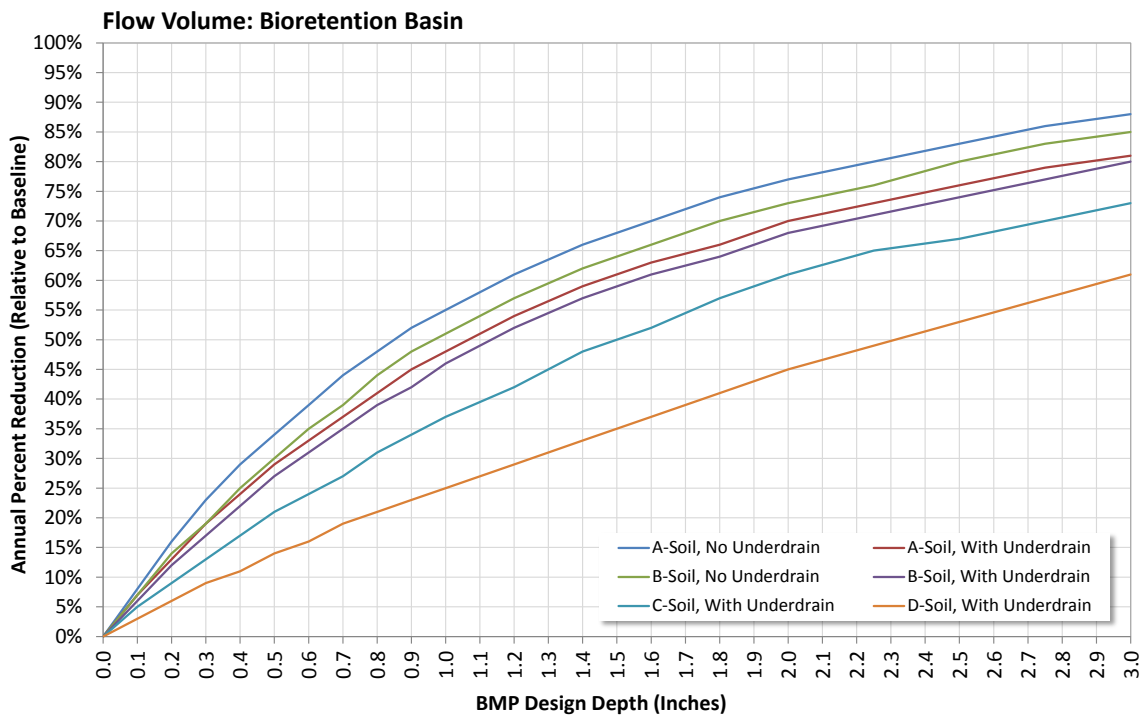
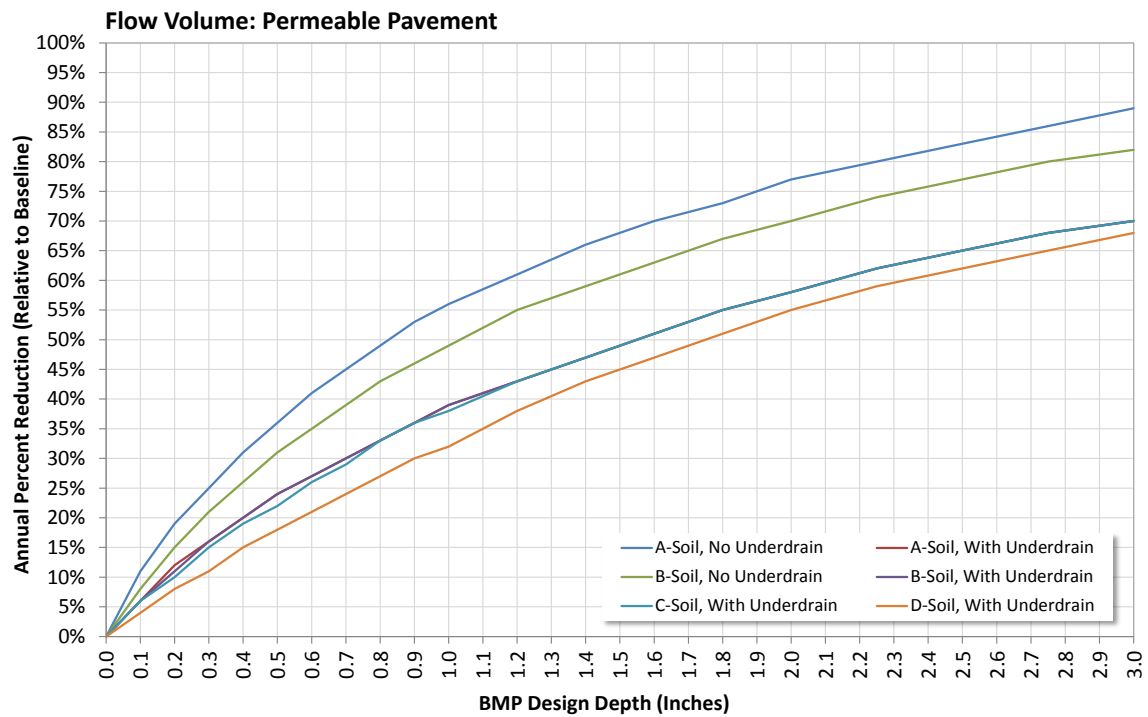
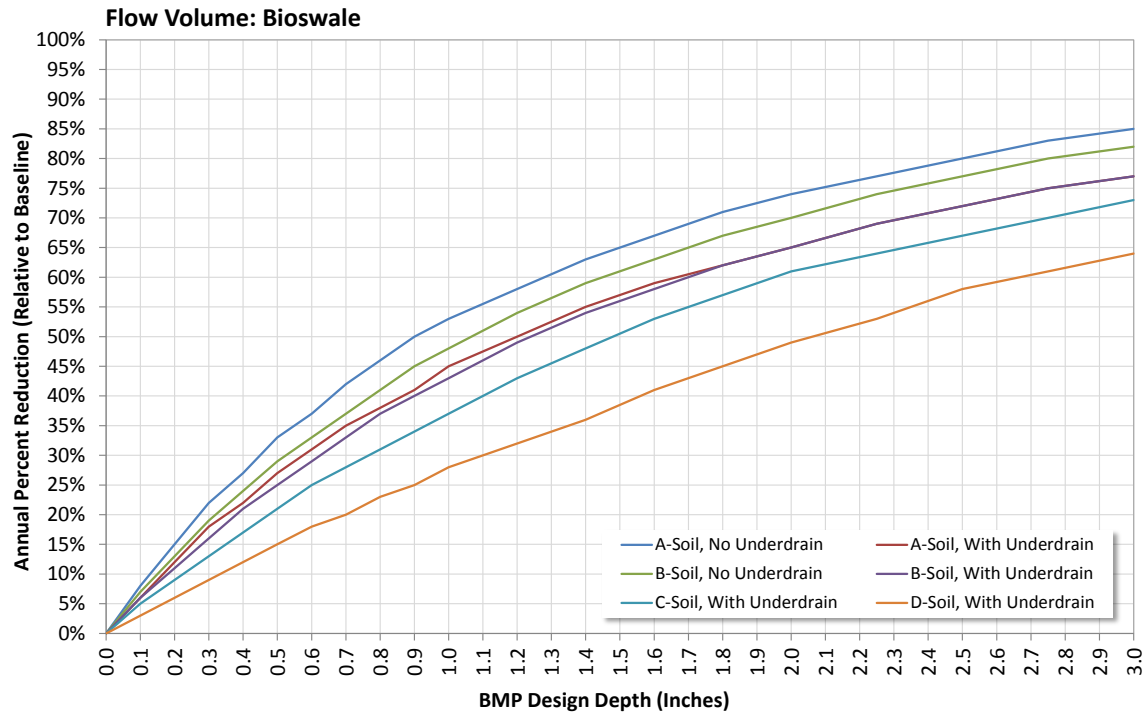


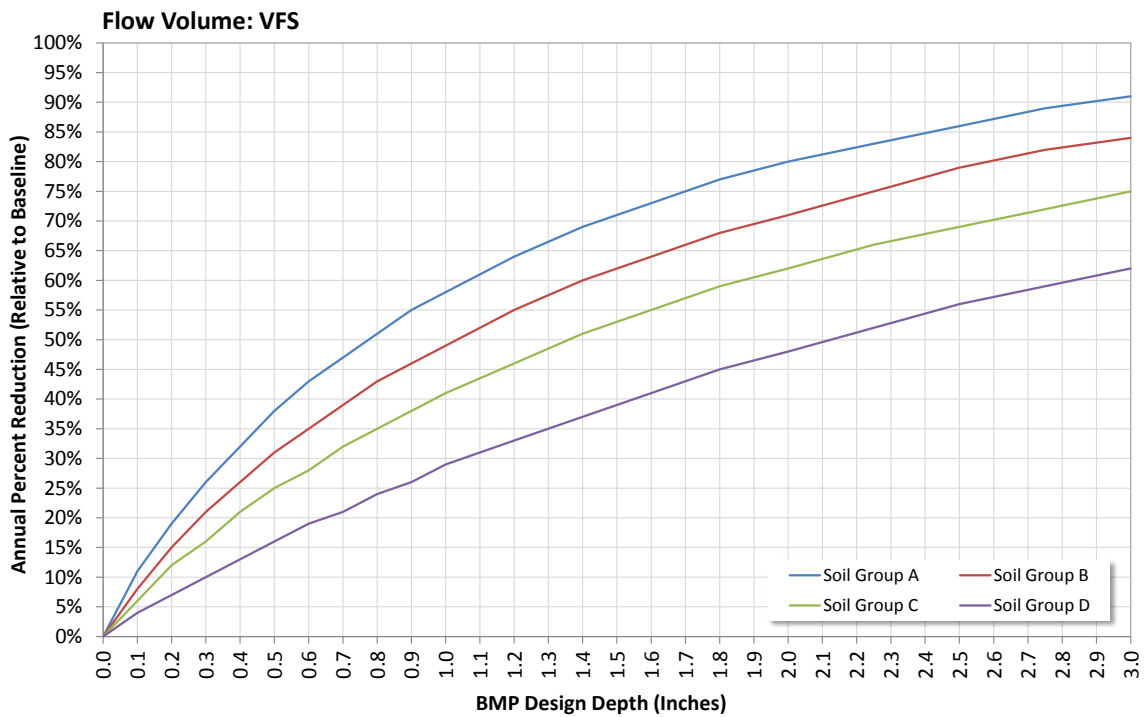
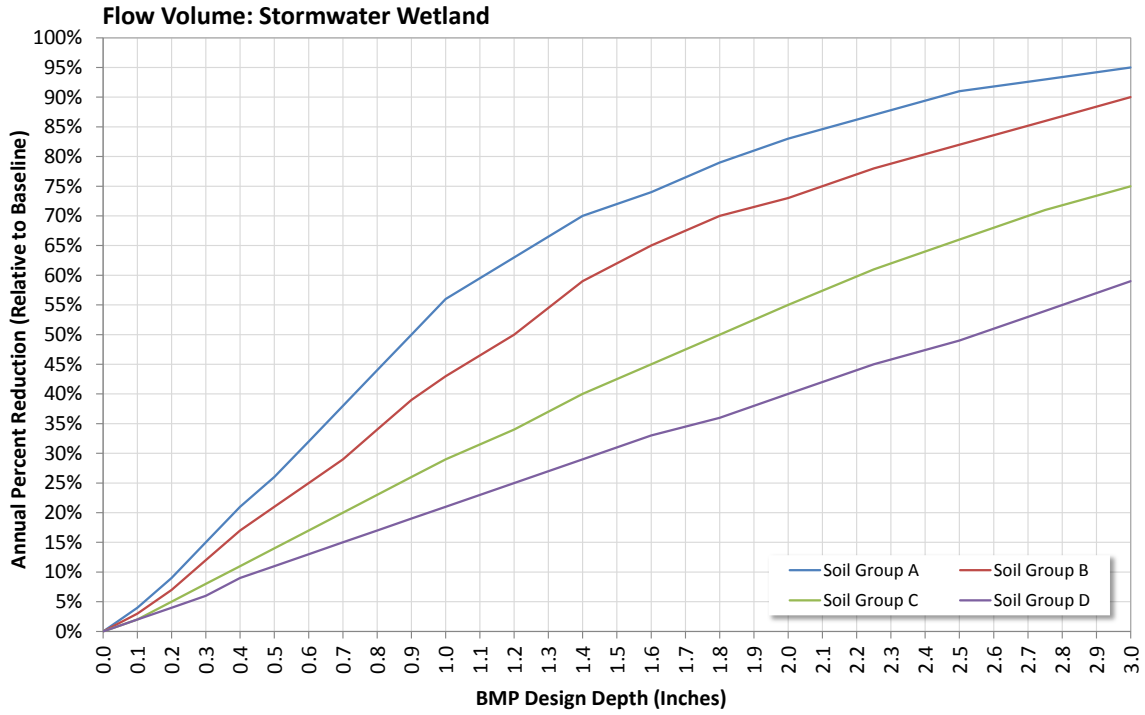
Figure A-4. Example performance curves showing flow volume reduction versus bioretention basin size.



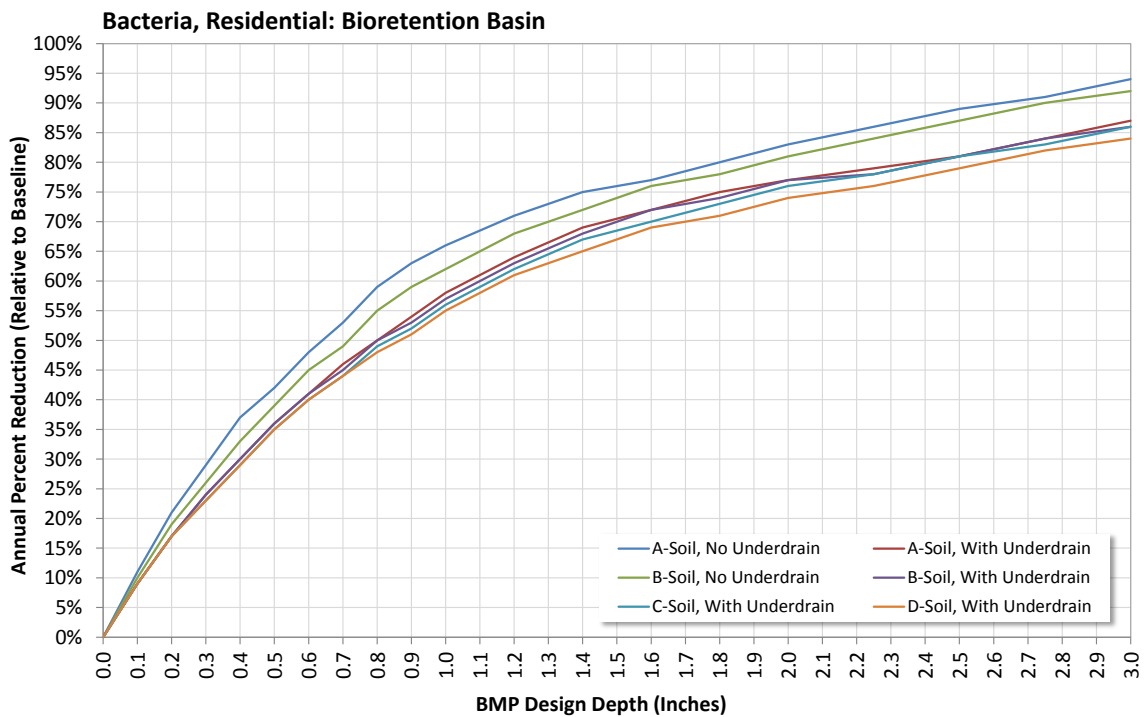
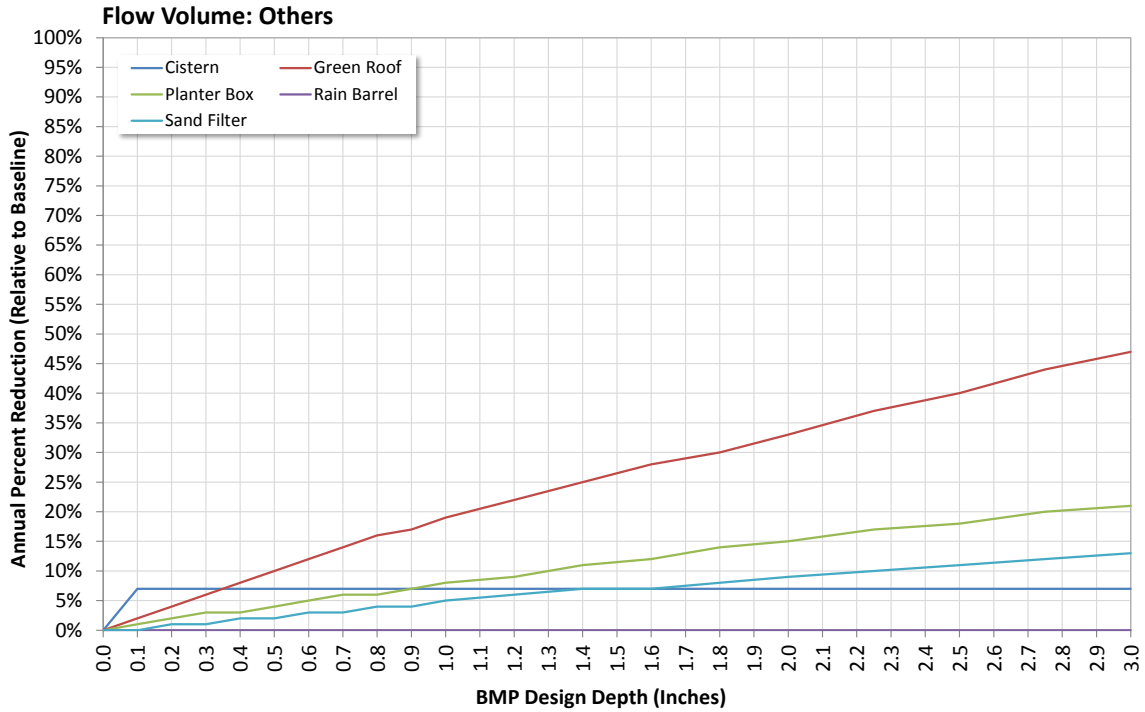
Appendix A.3 BMP Performance Curves



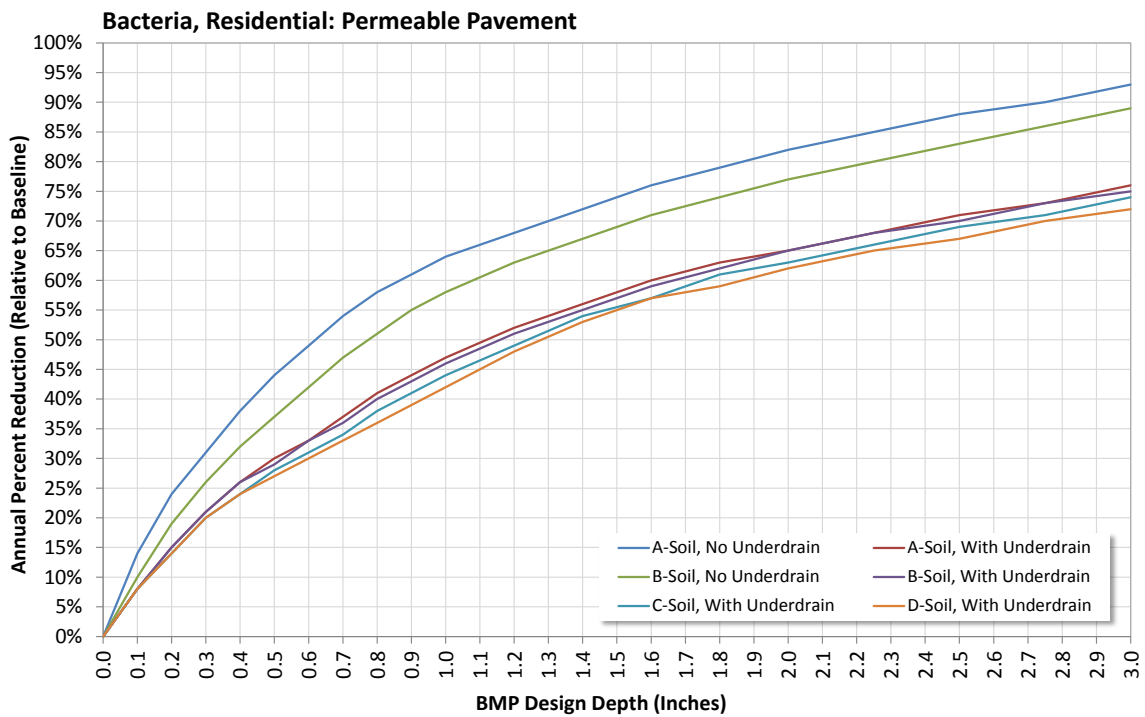
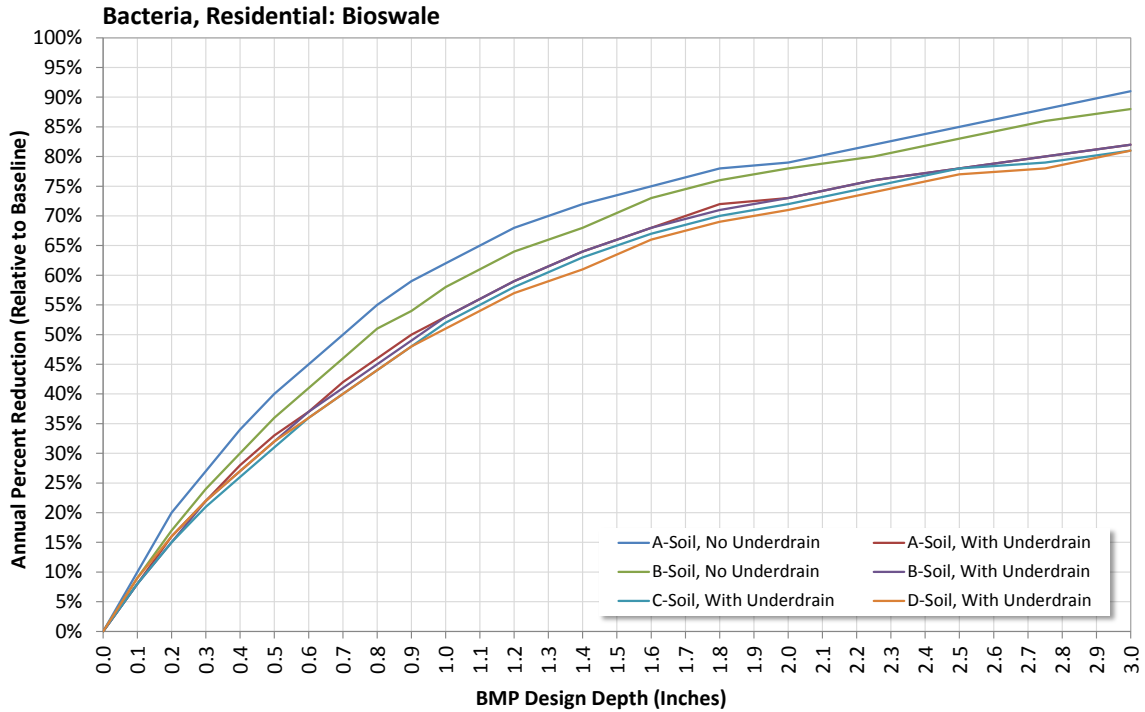
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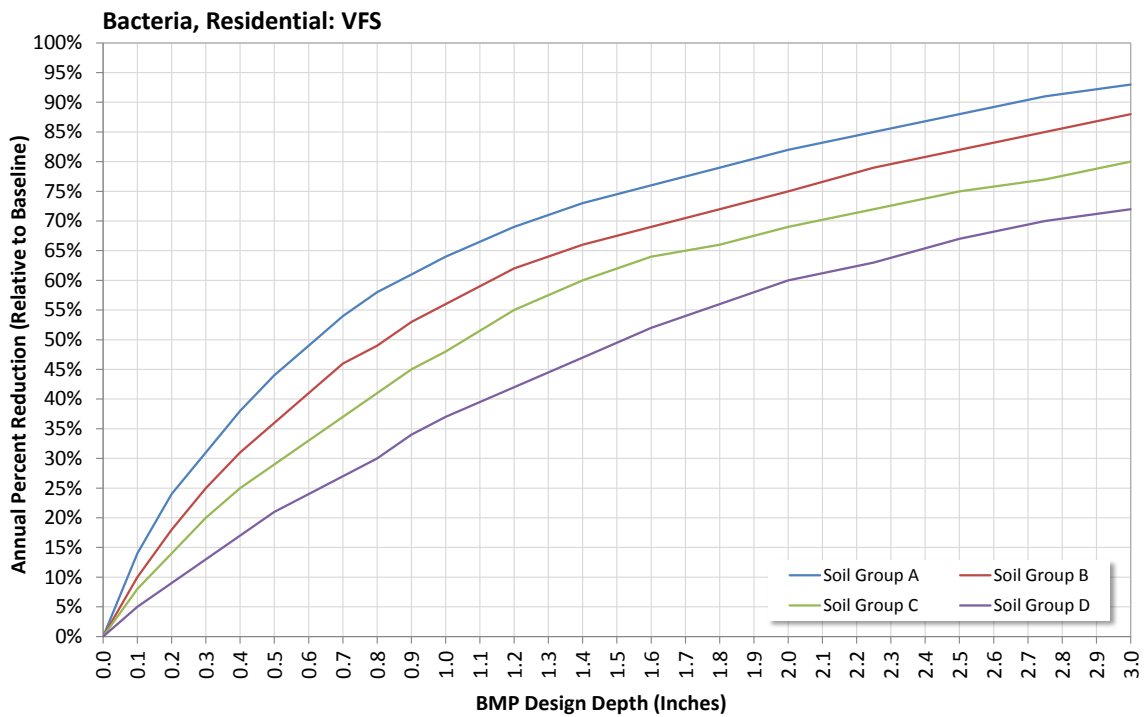
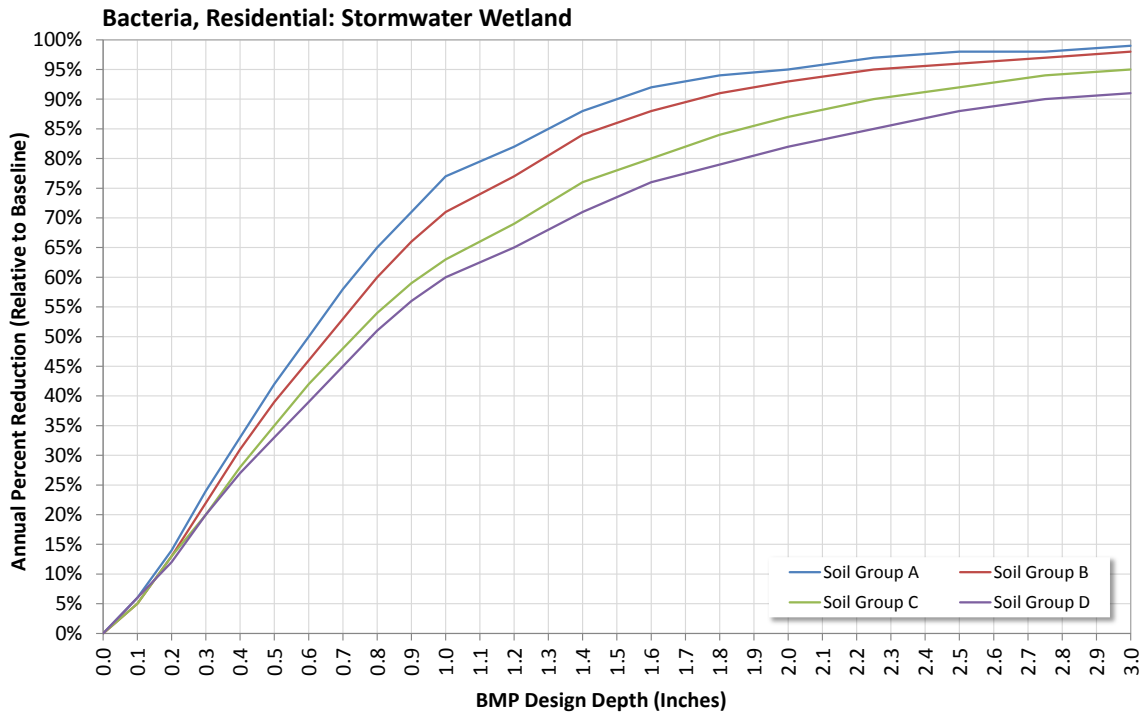
Appendix A.3 BMP Performance Curves



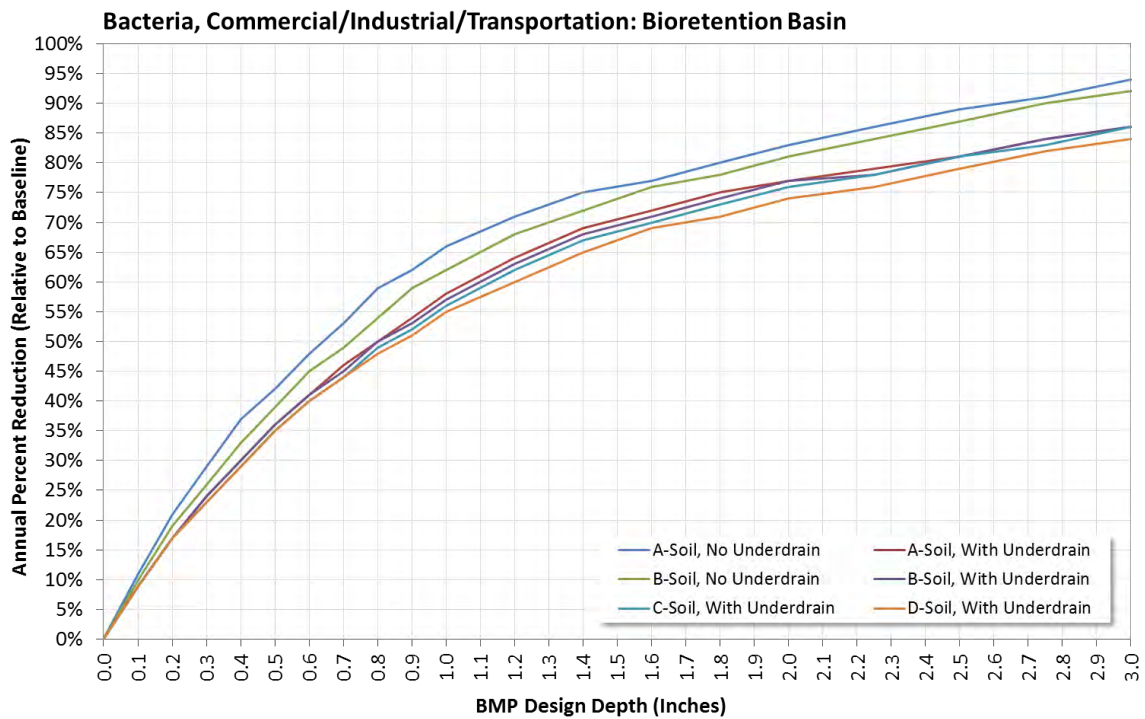
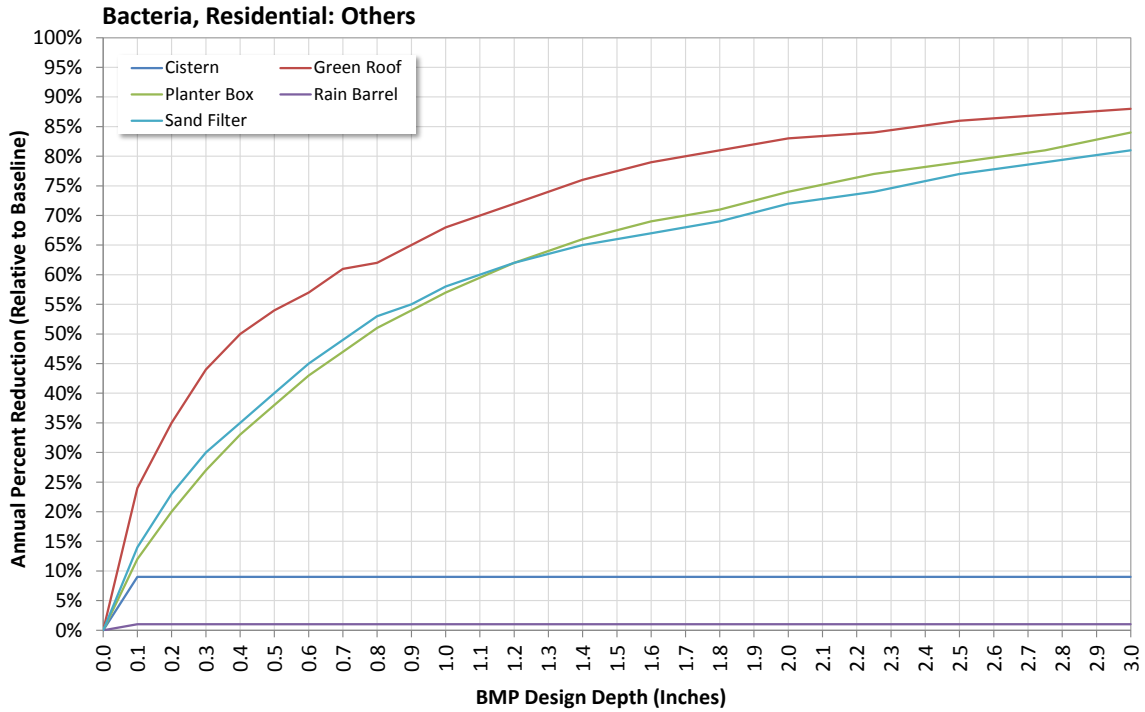
Appendix A.3 BMP Performance Curves



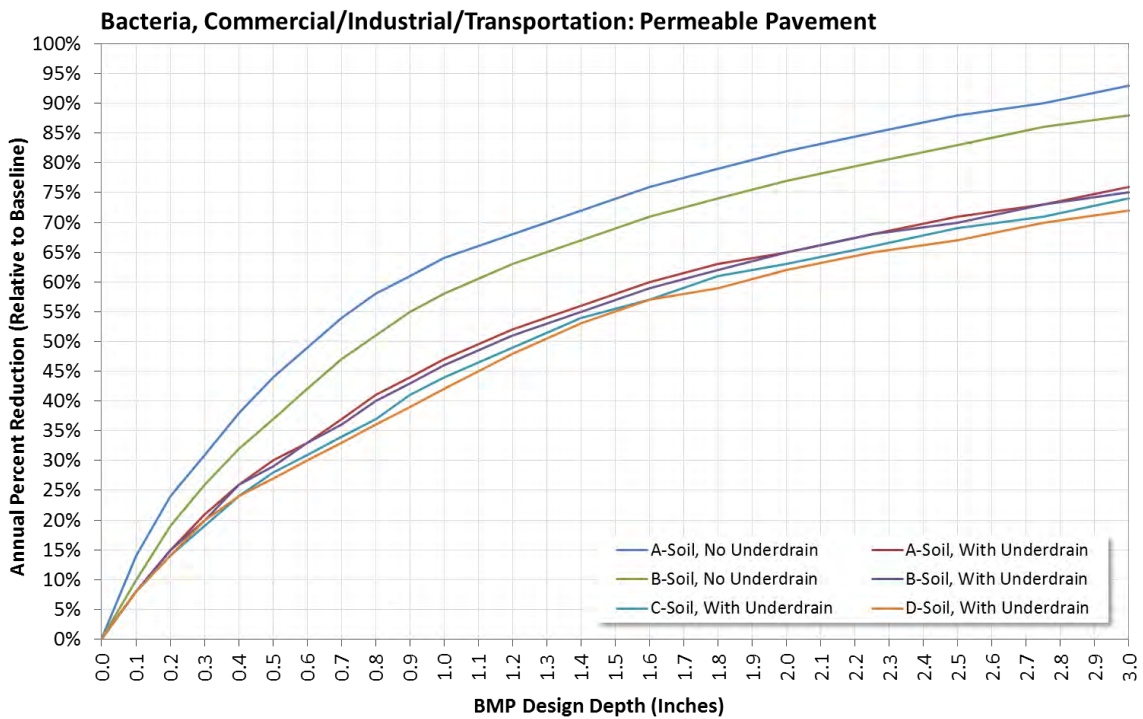
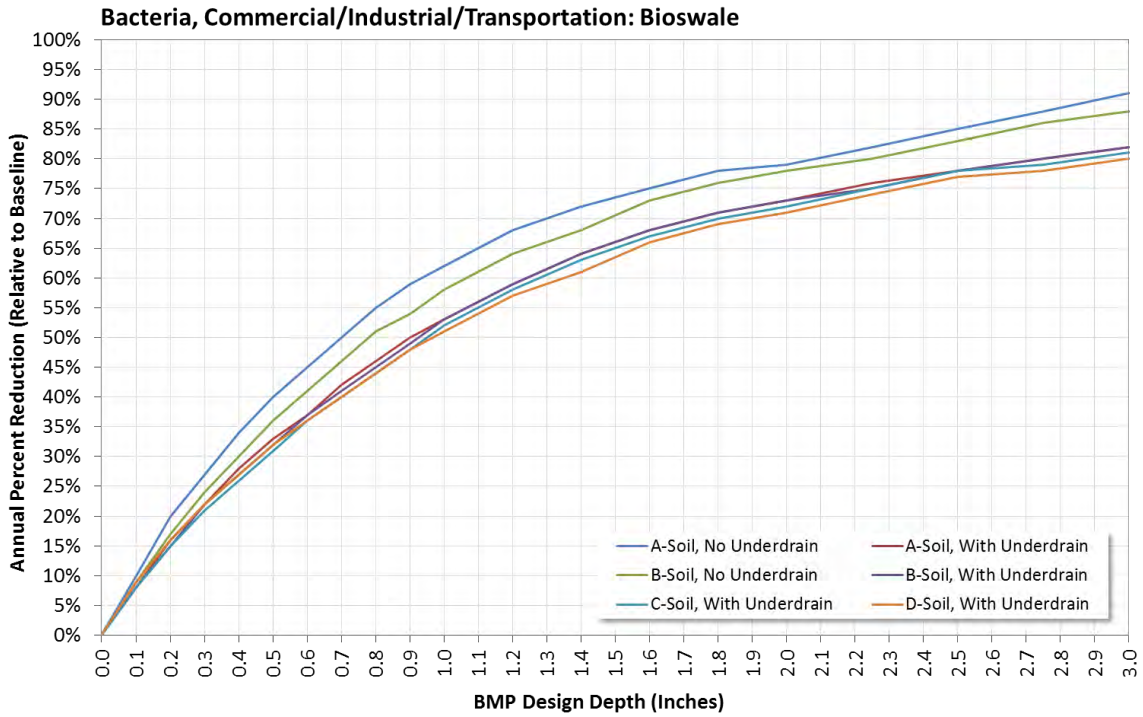
Appendix A.3 BMP Performance Curves



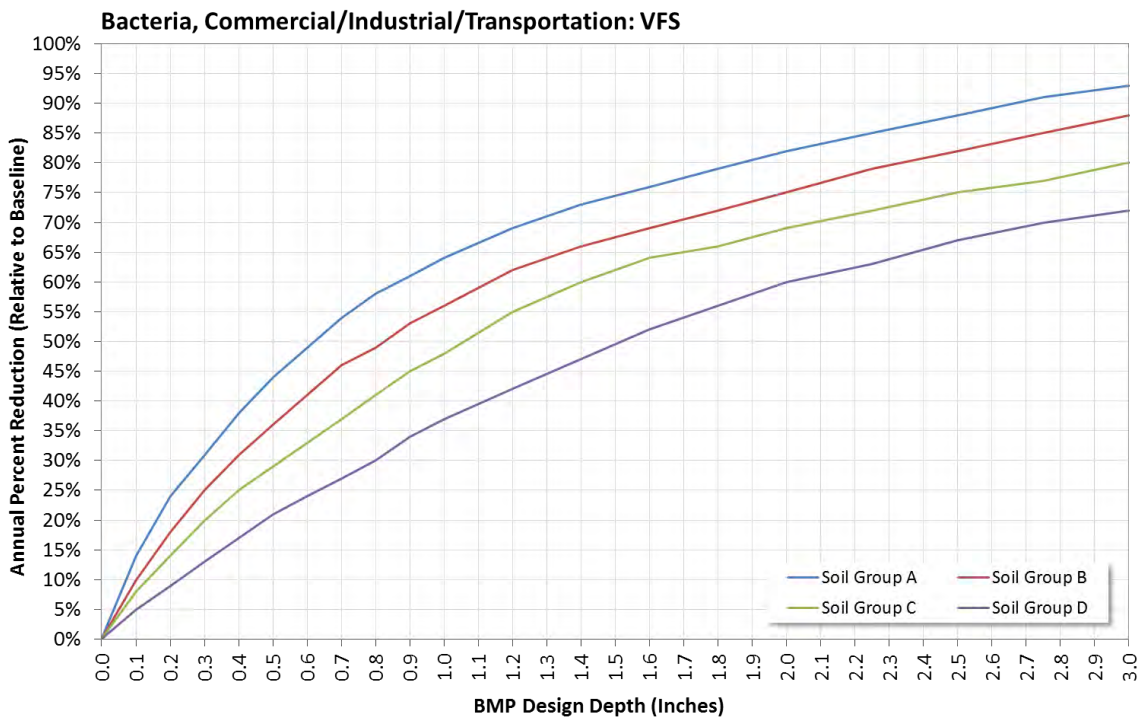
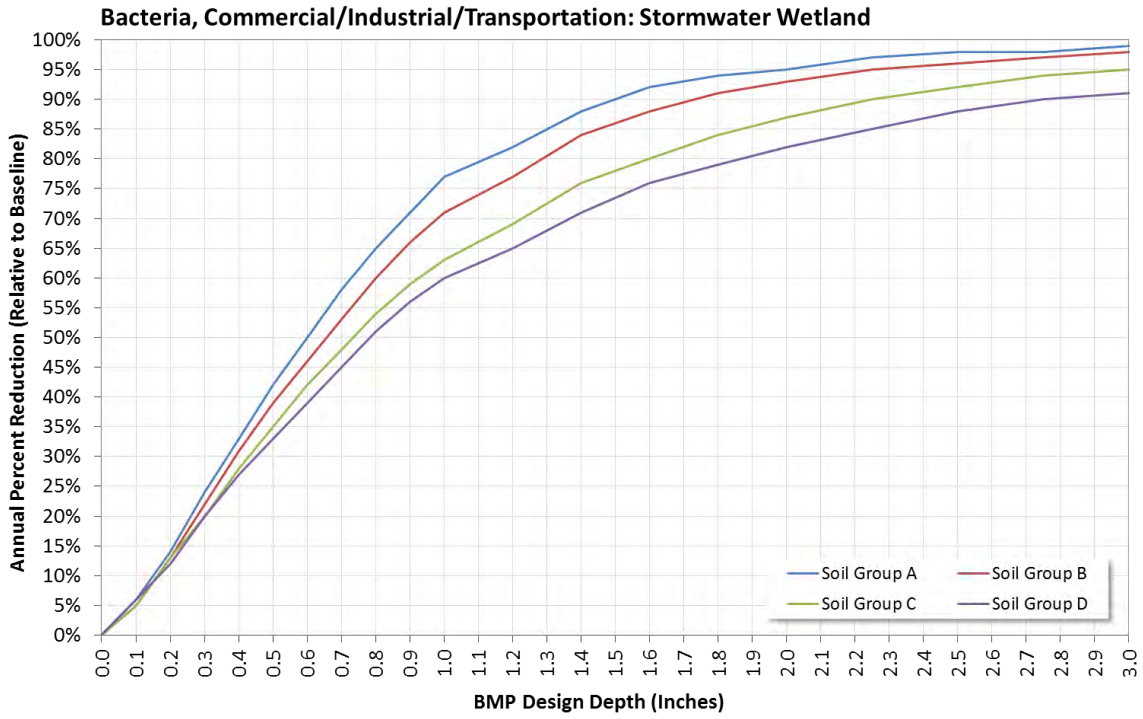
Appendix A.3 BMP Performance Curves



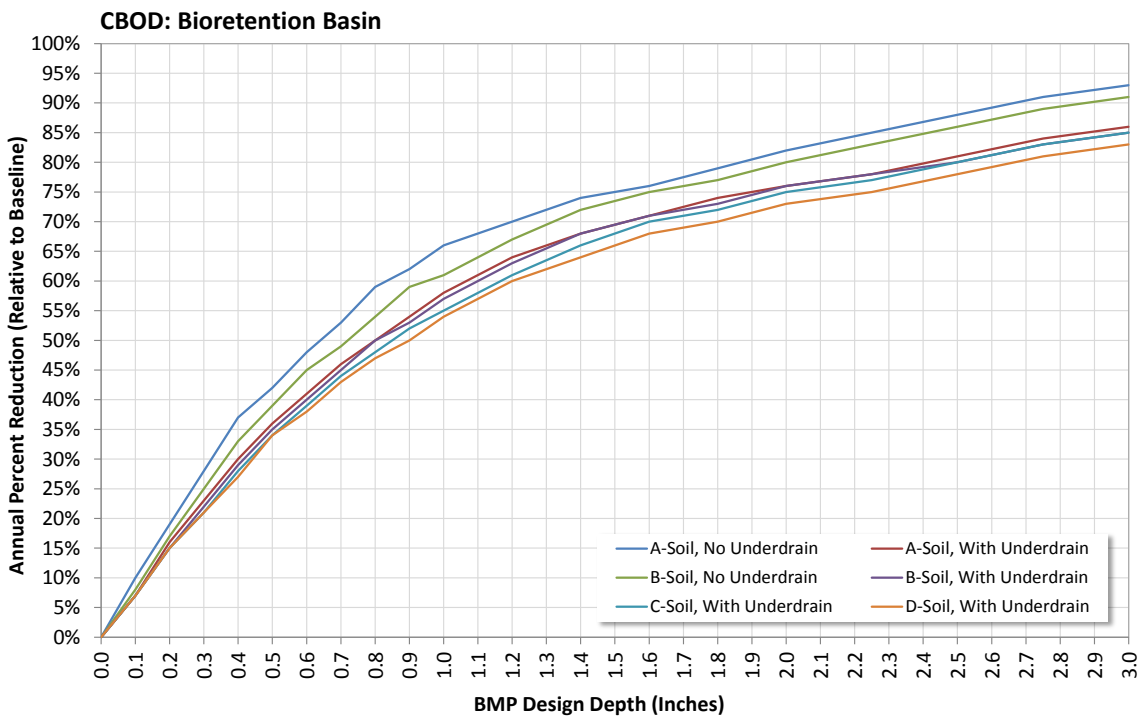
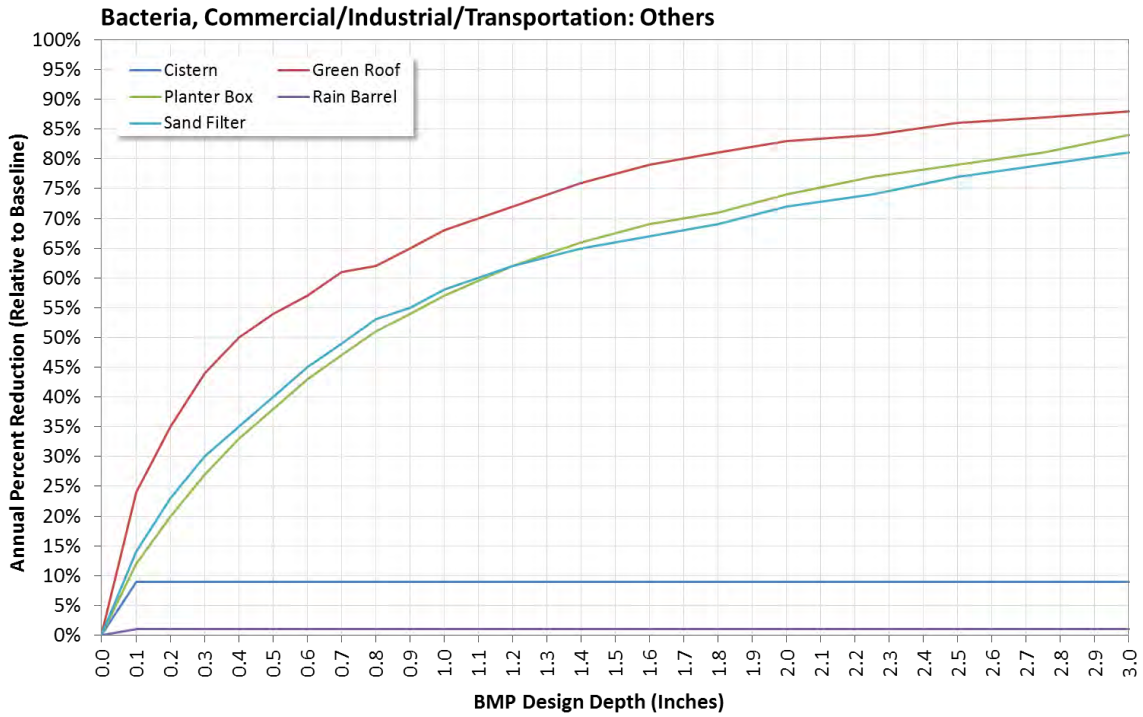
Appendix A.3 BMP Performance Curves



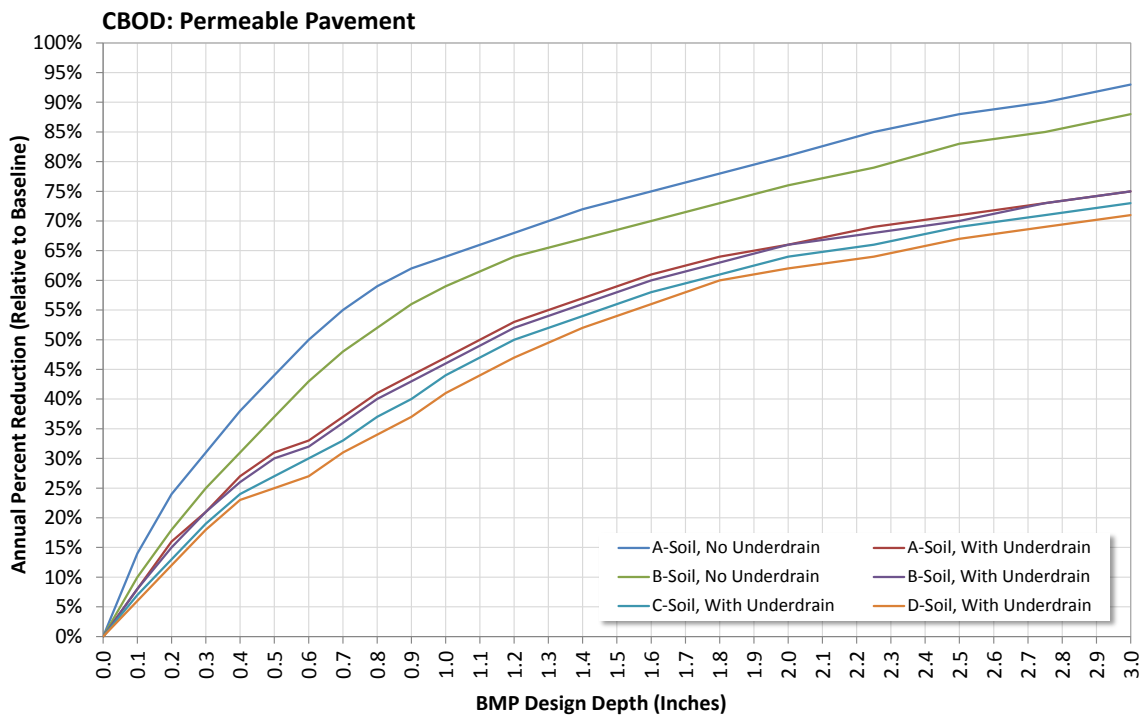
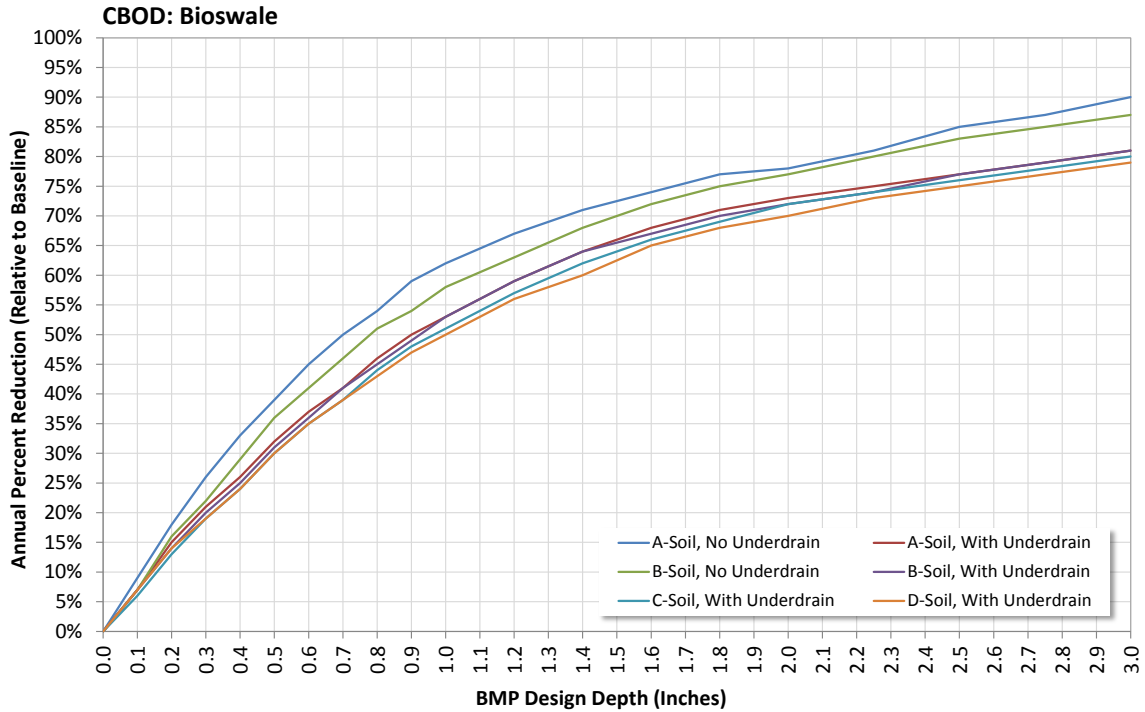
Appendix A.3 BMP Performance Curves



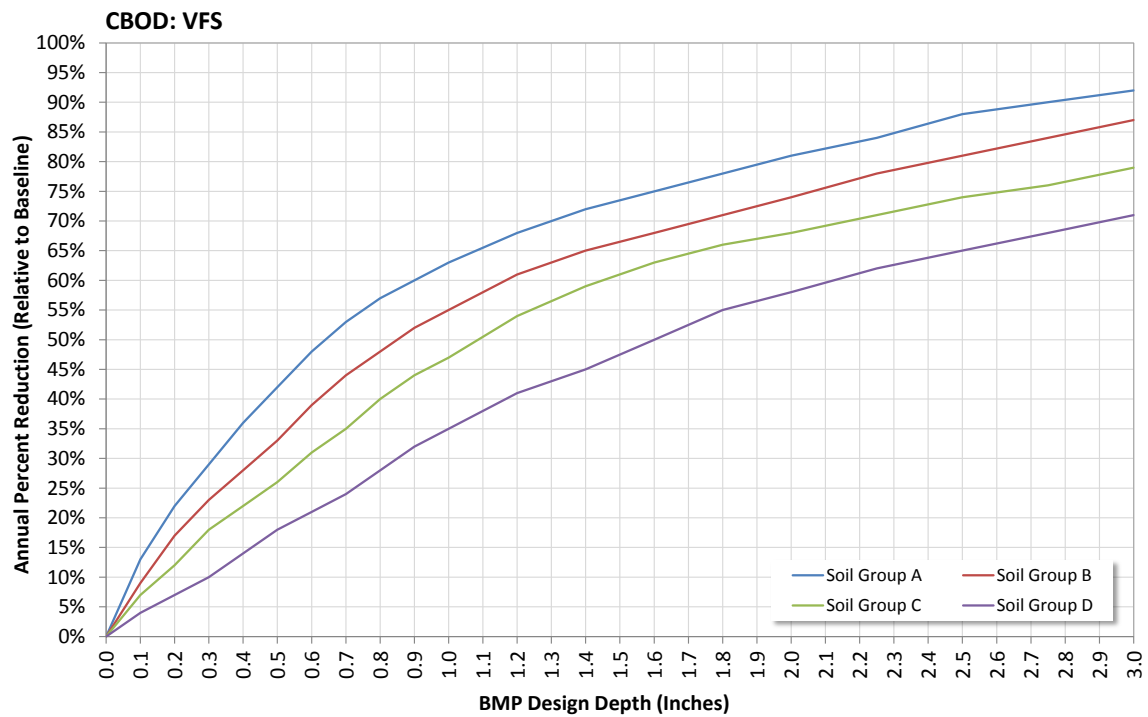
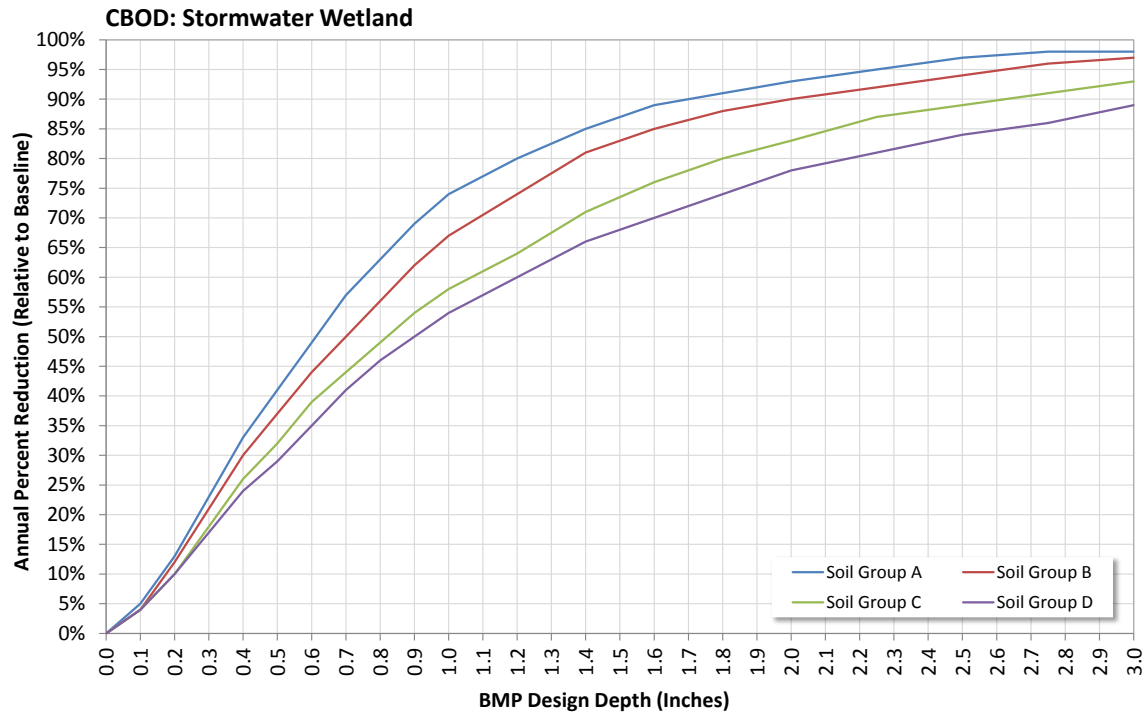
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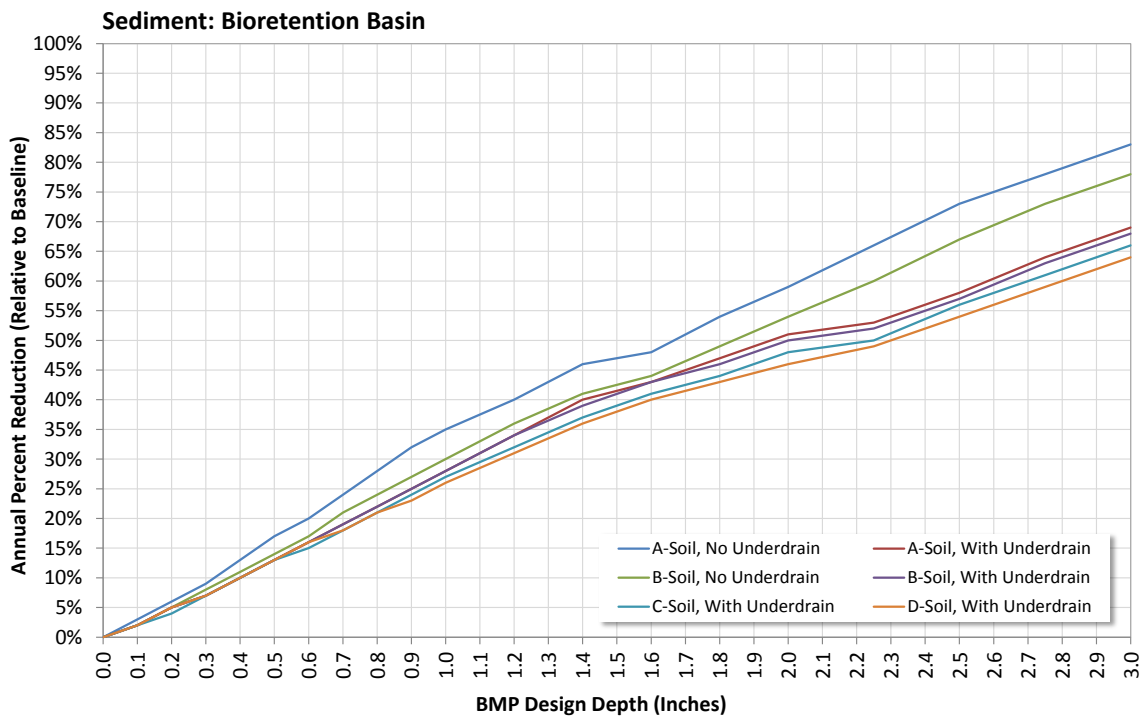
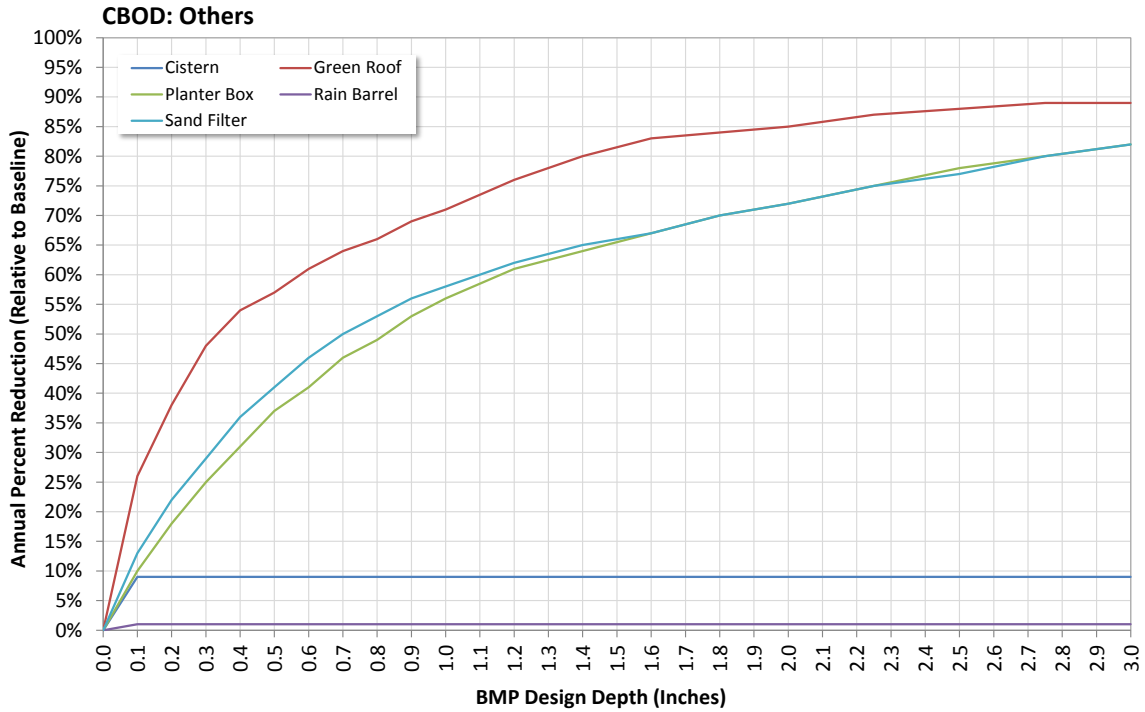
Appendix A.3 BMP Performance Curves



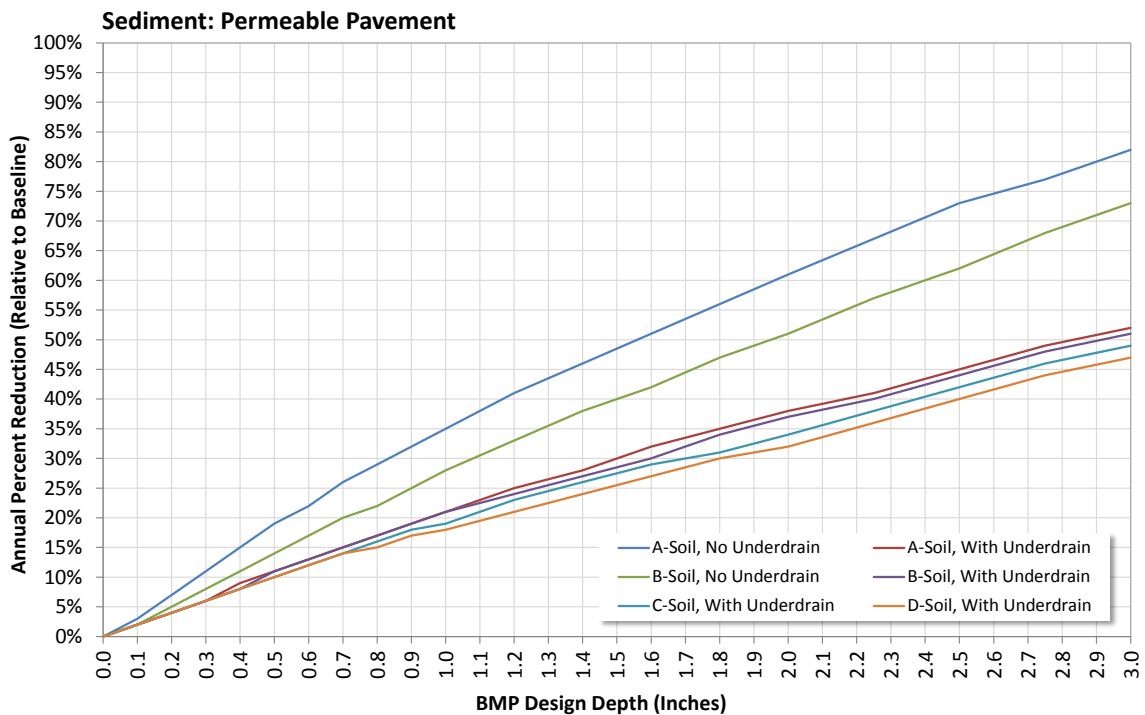
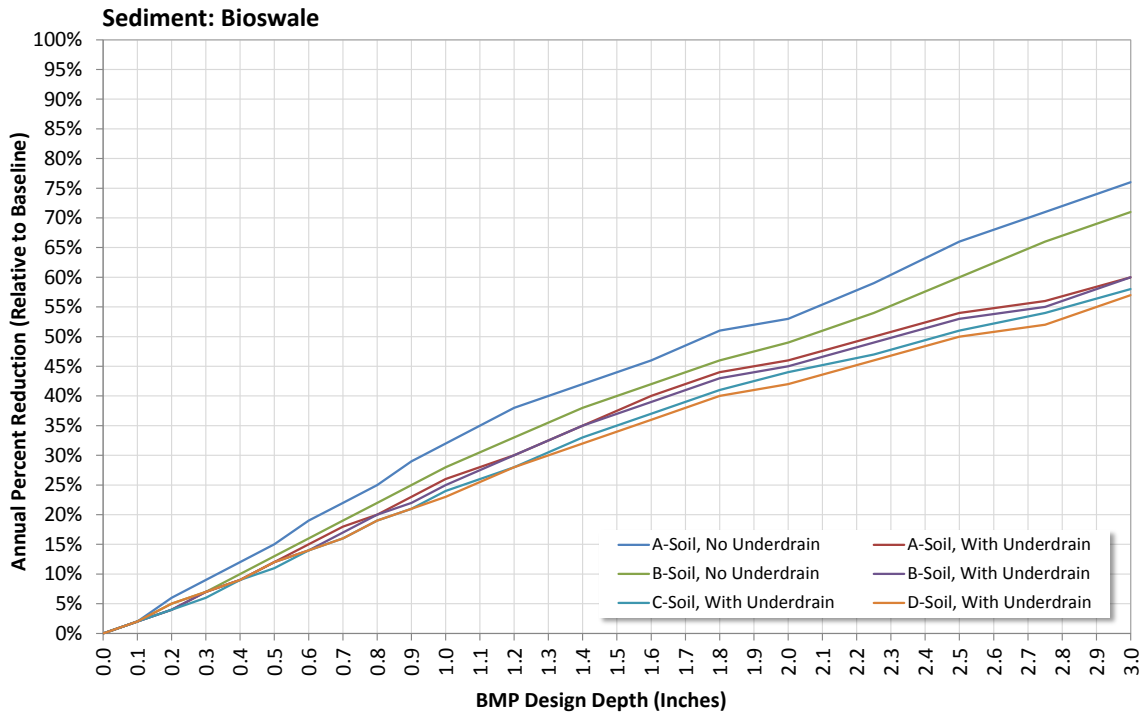
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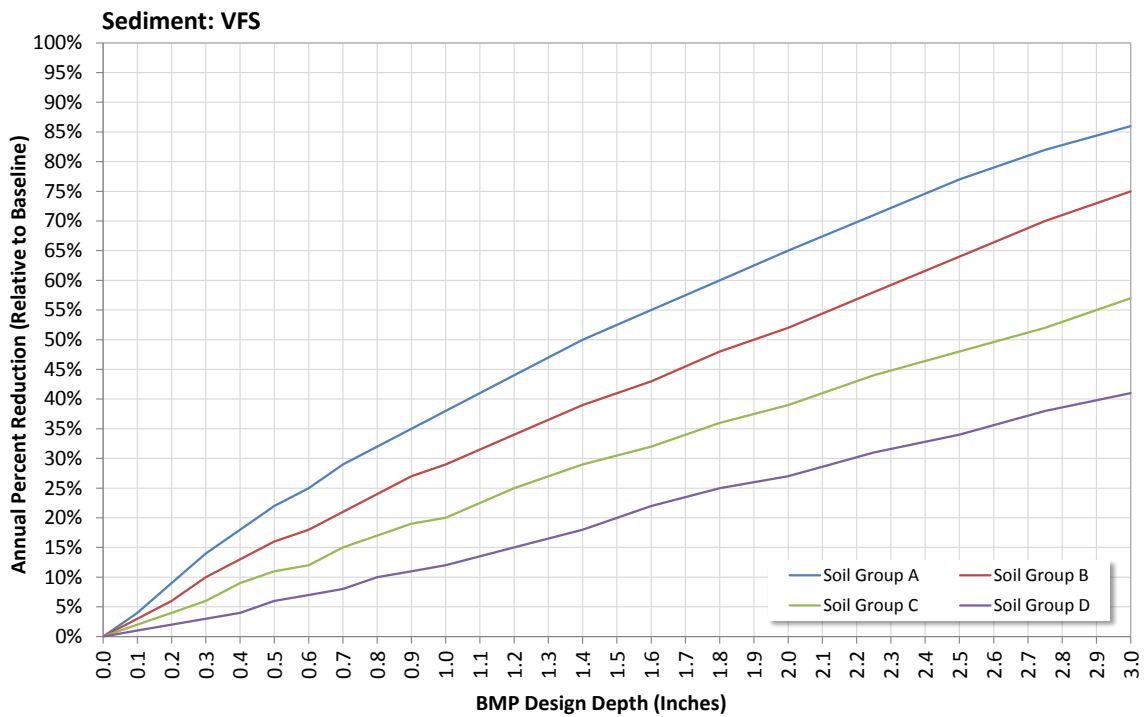
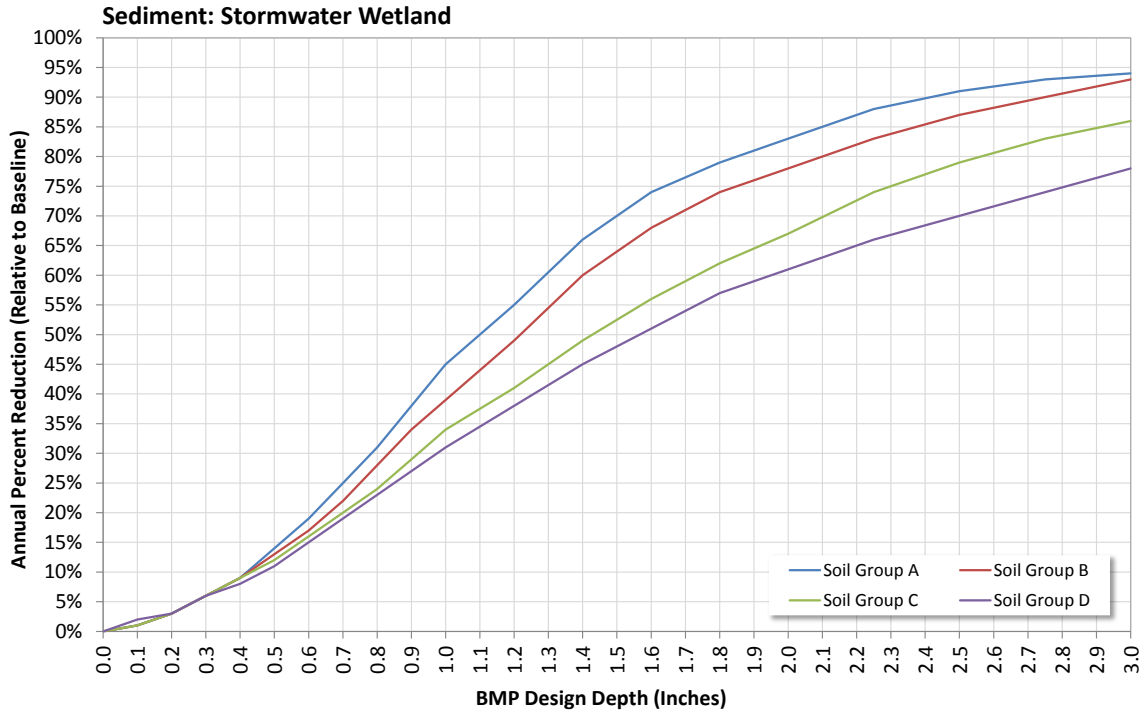
Appendix A.3 BMP Performance Curves



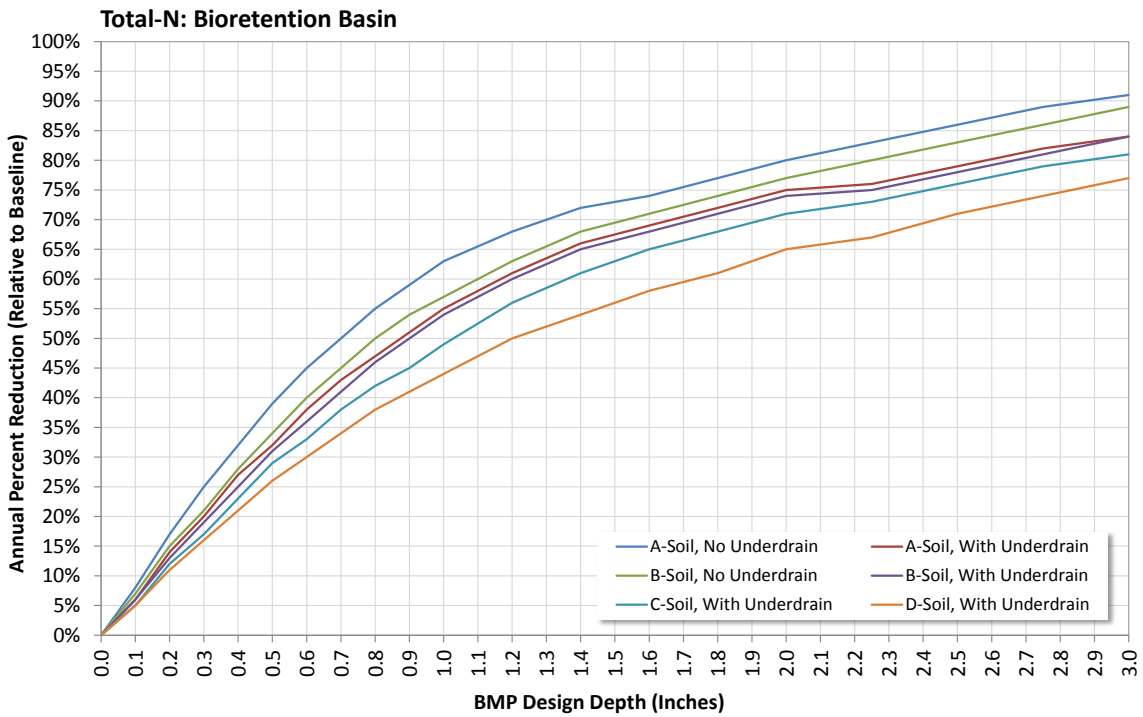
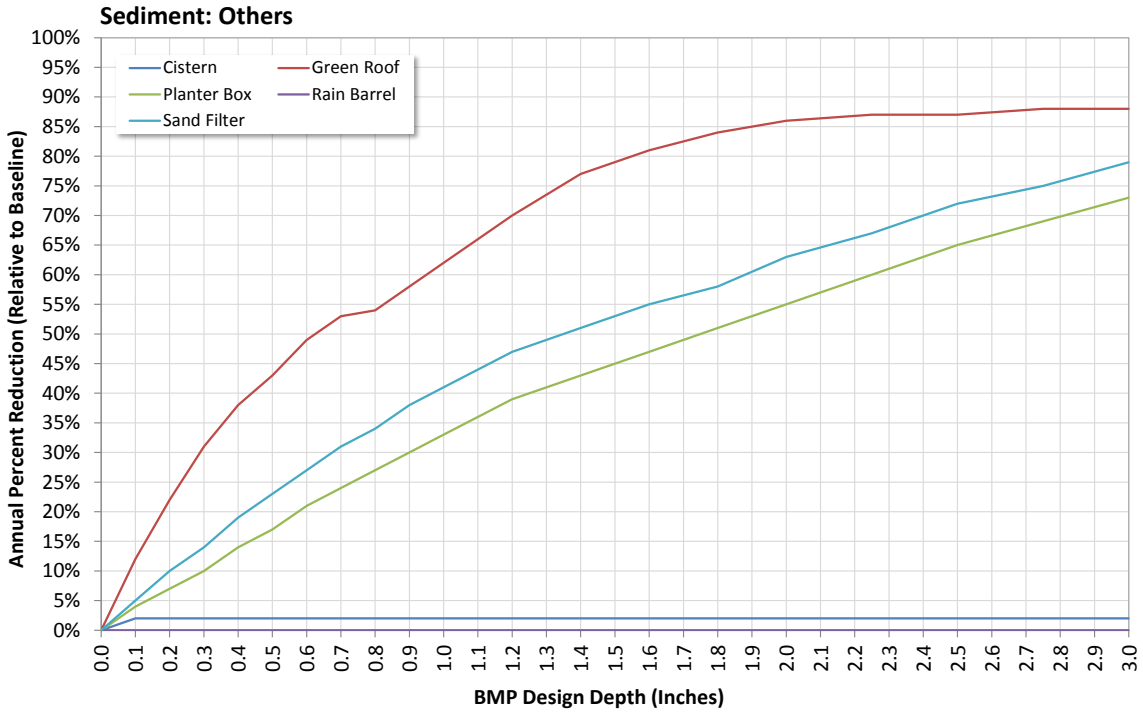
Appendix A.3 BMP Performance Curves



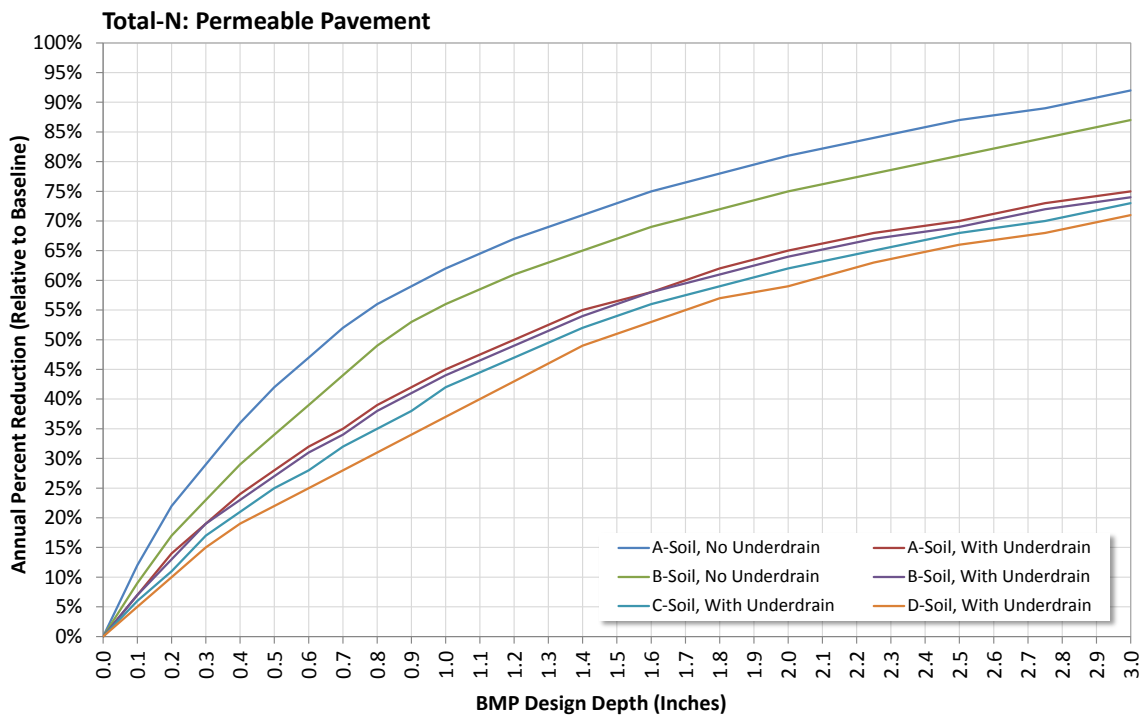
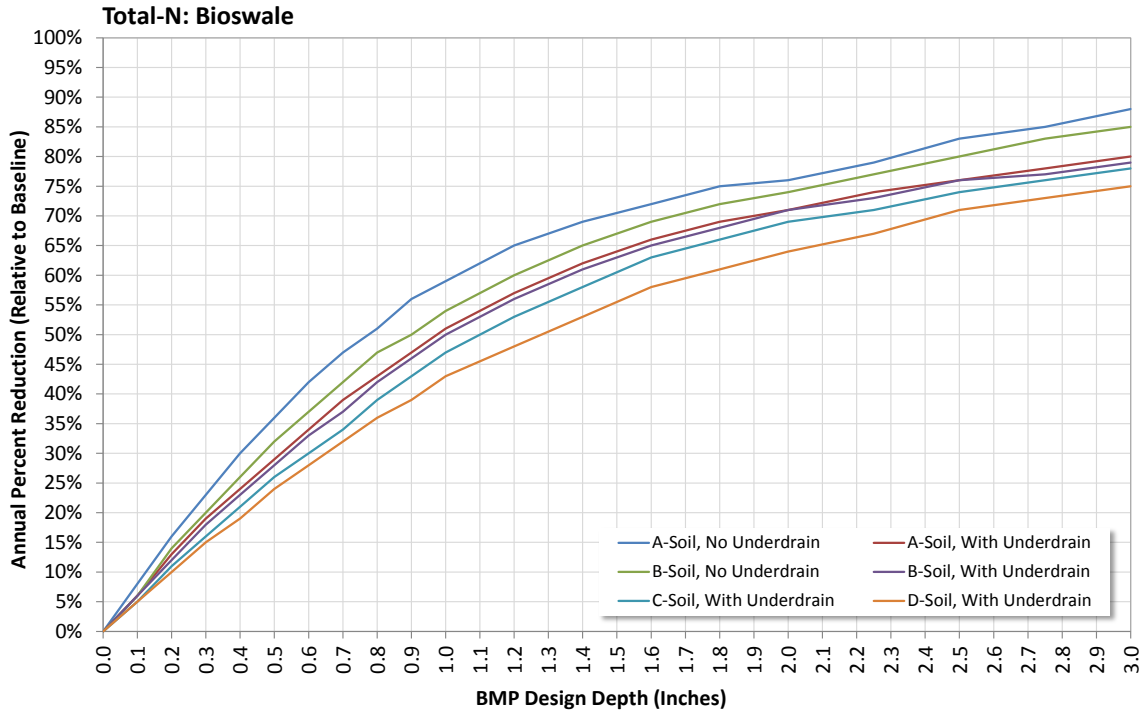
Appendix A.3 BMP Performance Curves



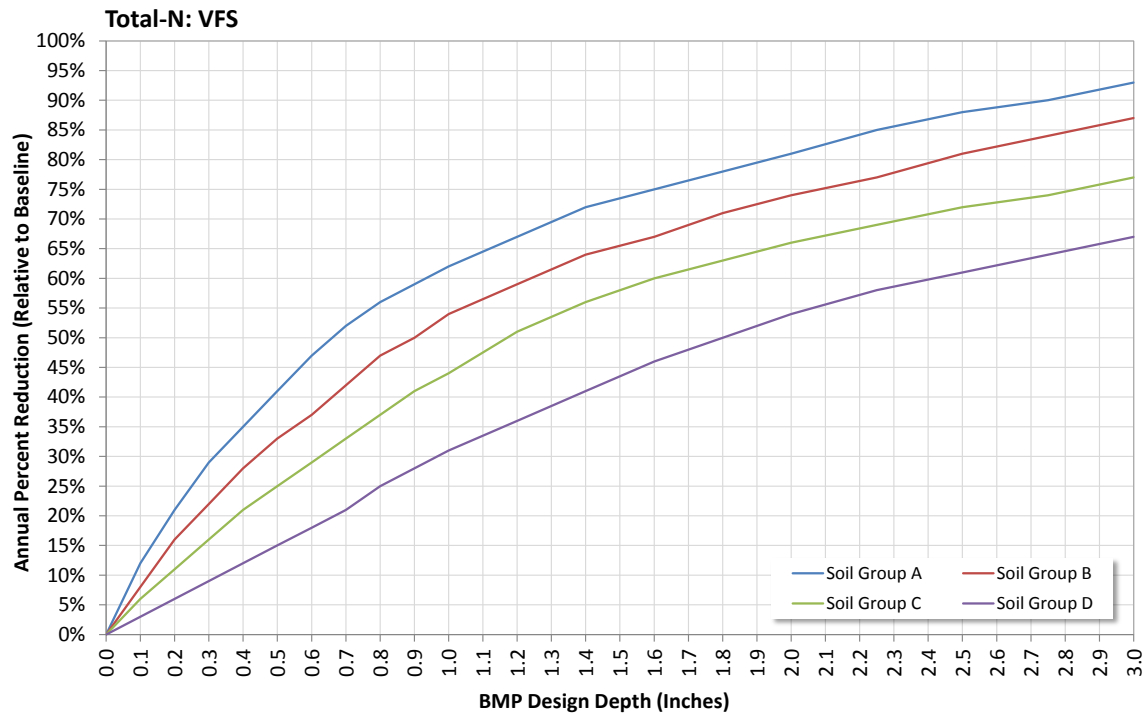
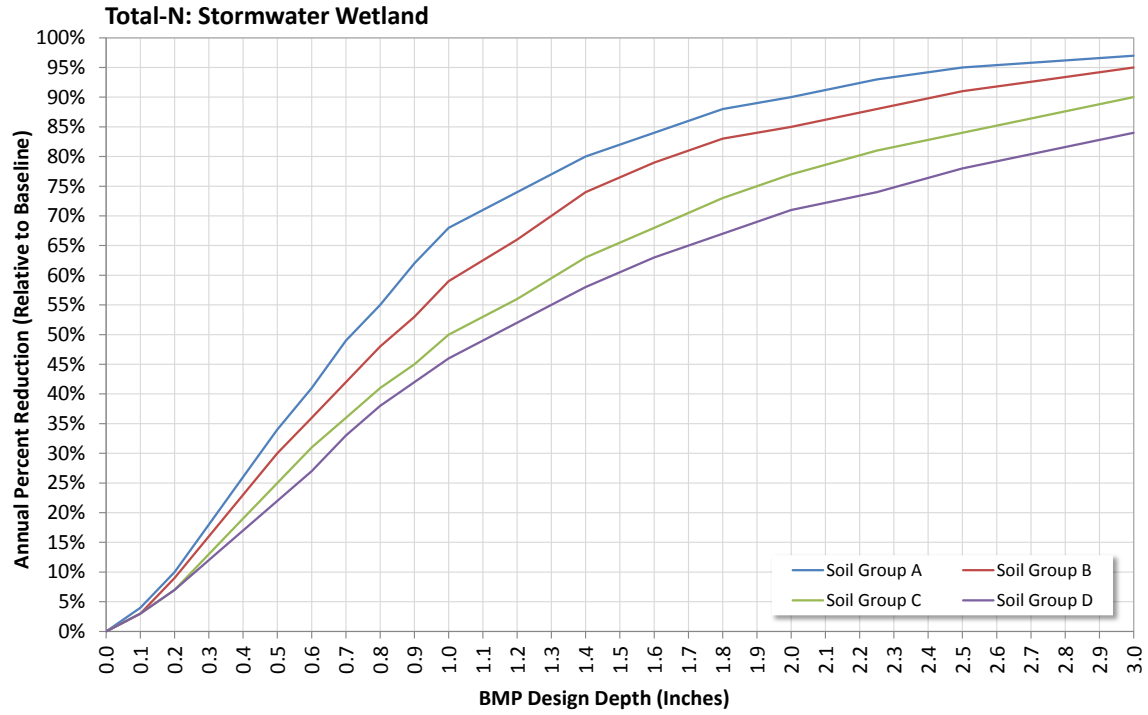
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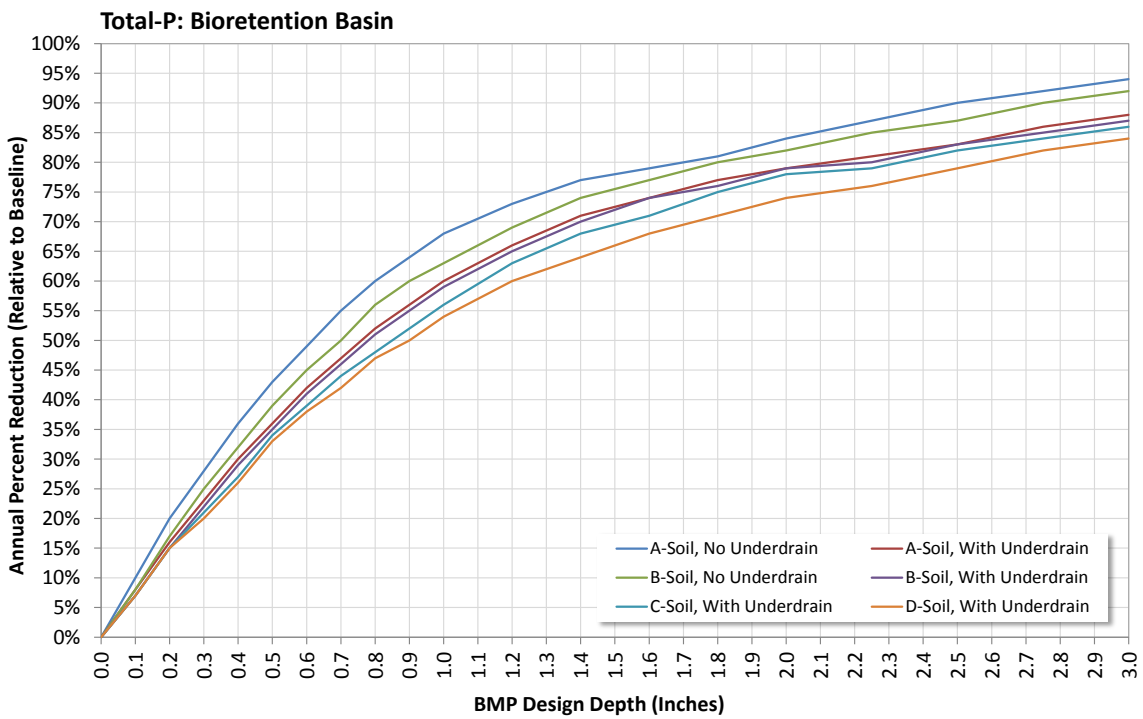
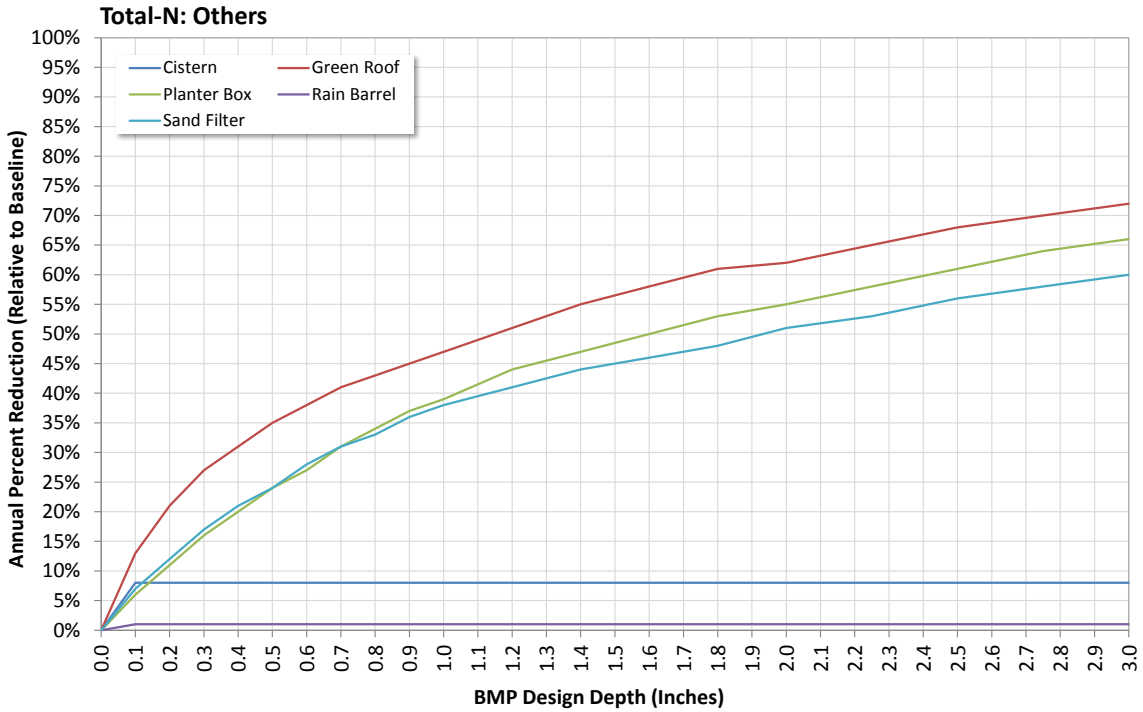
Appendix A.3 BMP Performance Curves



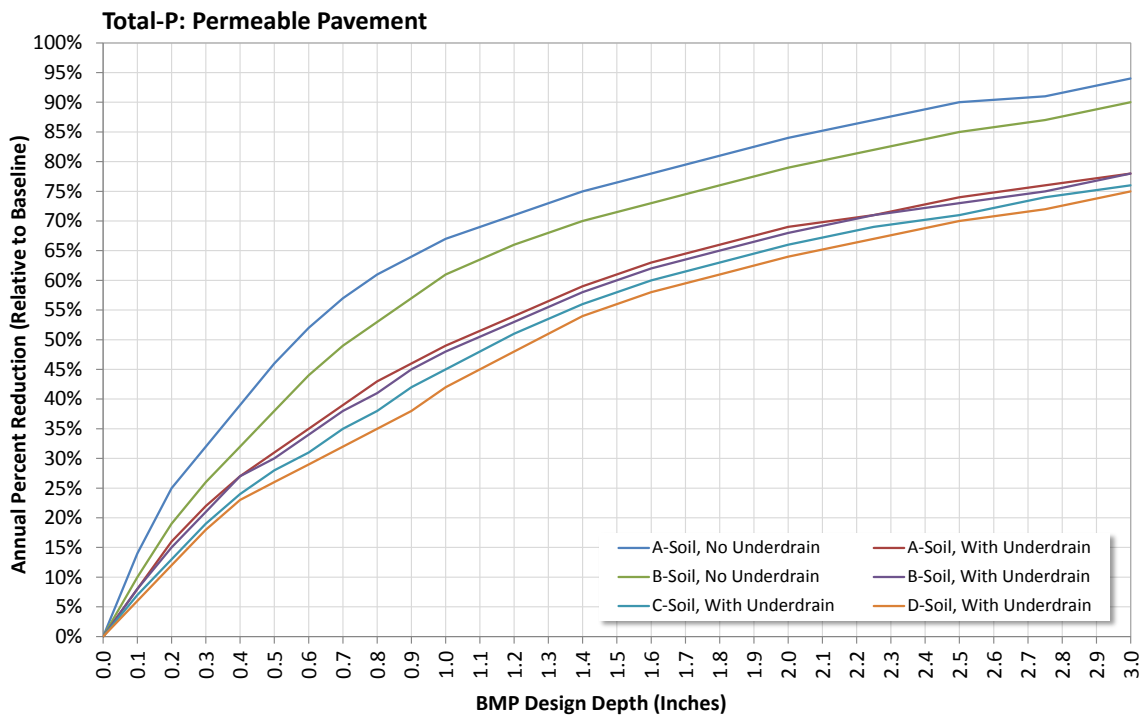
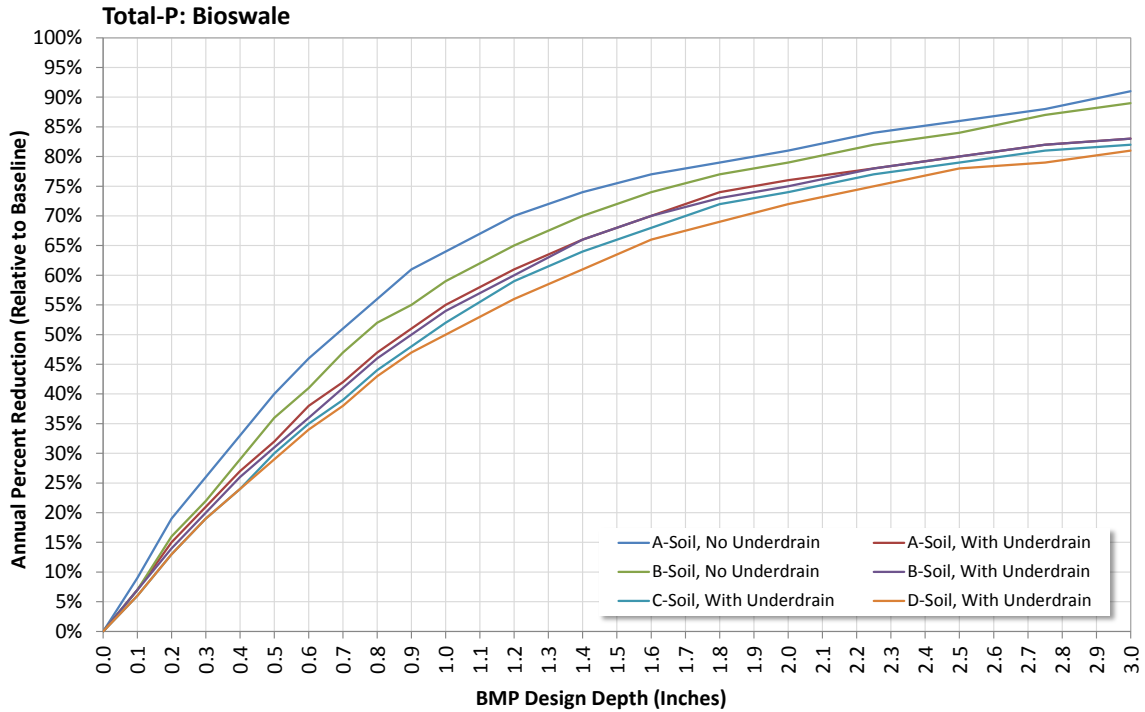
Appendix A.3 BMP Performance Curves



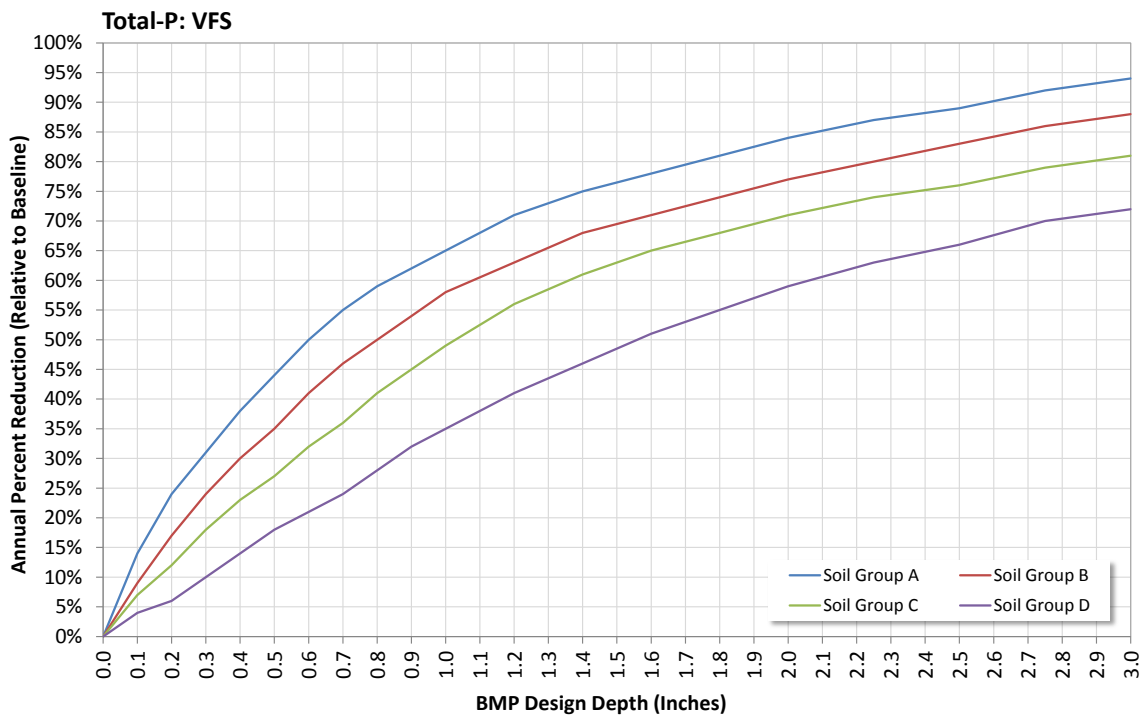
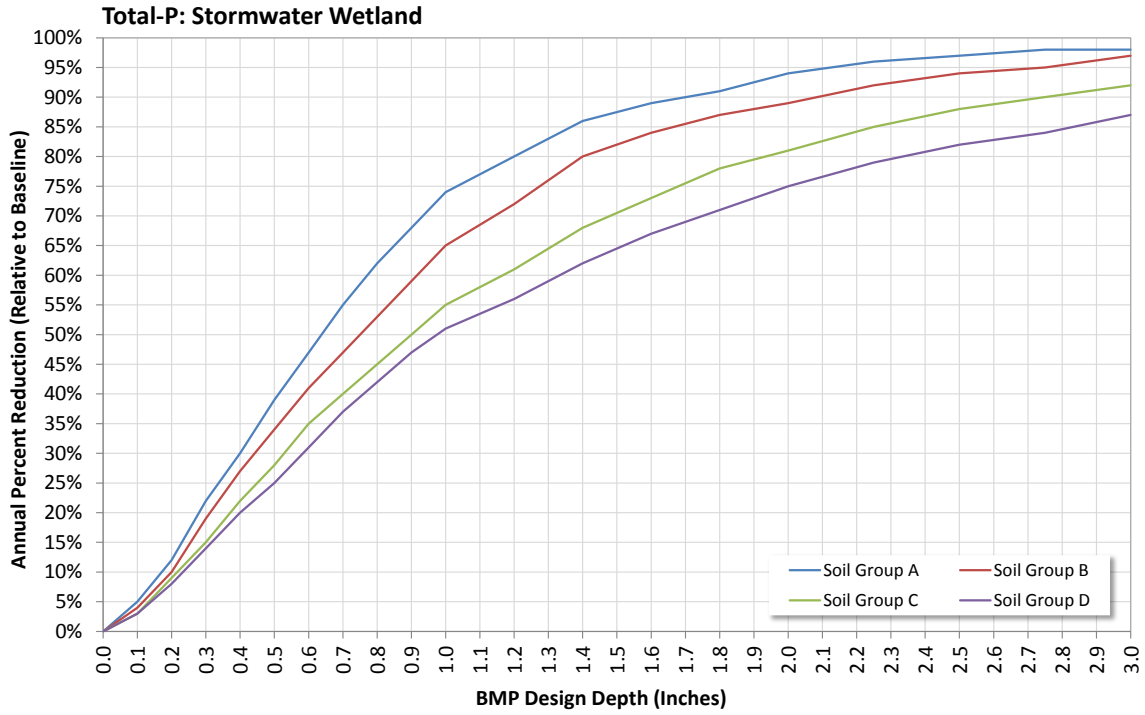
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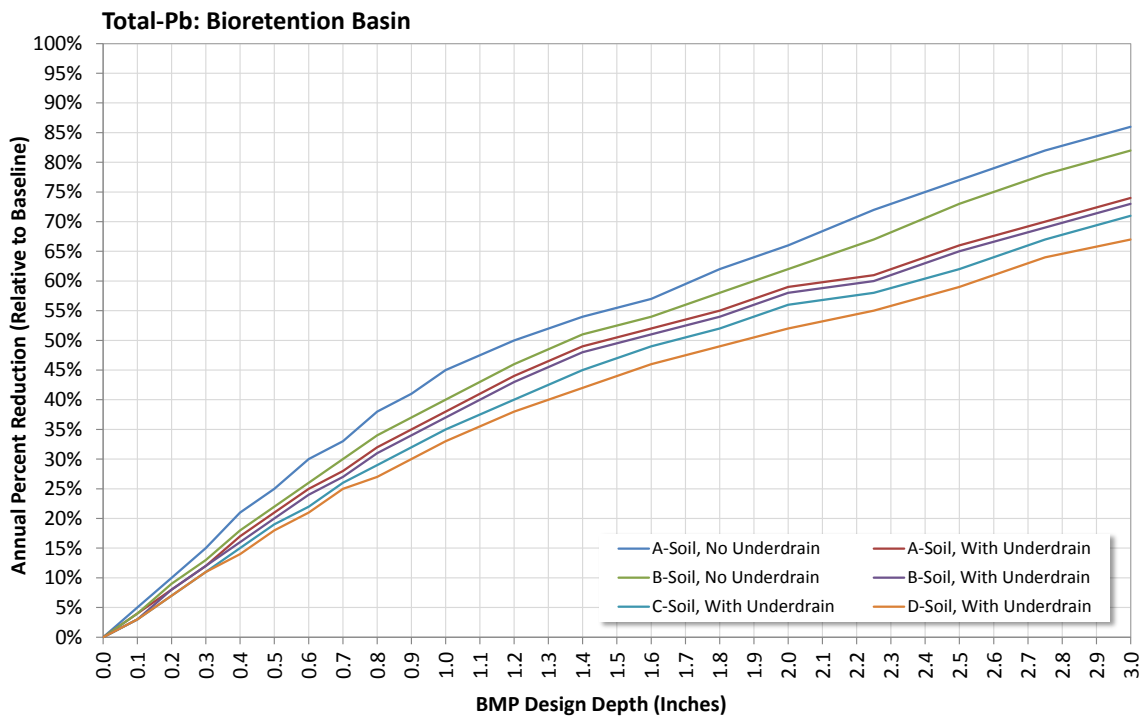
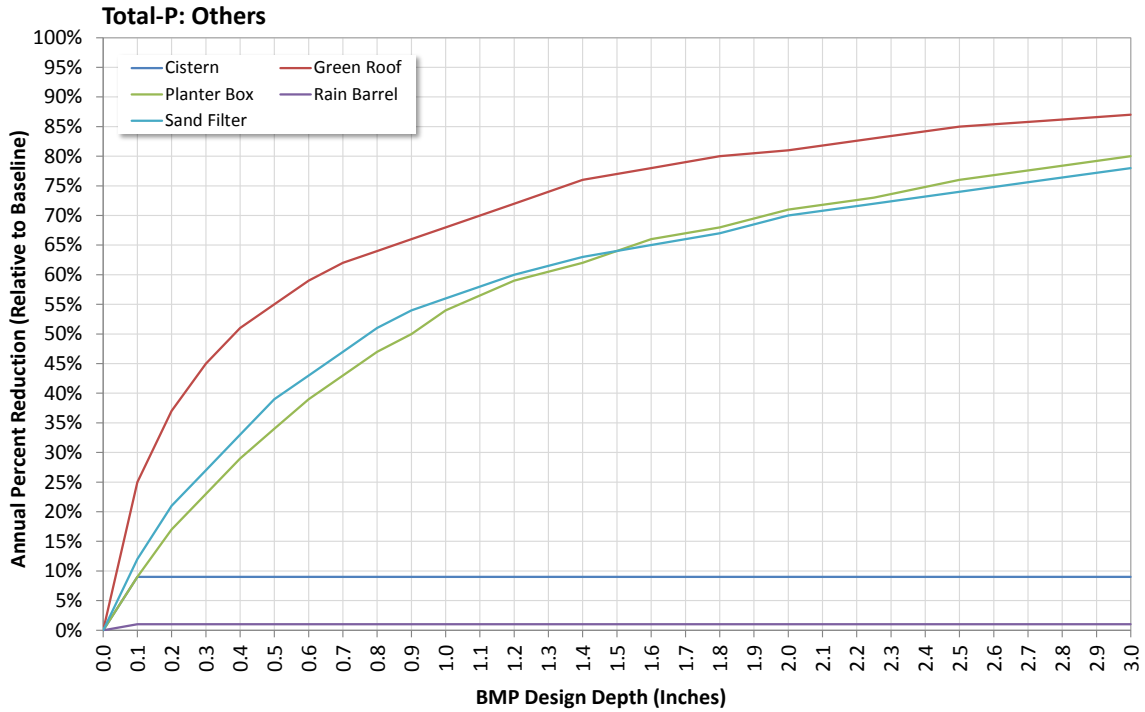
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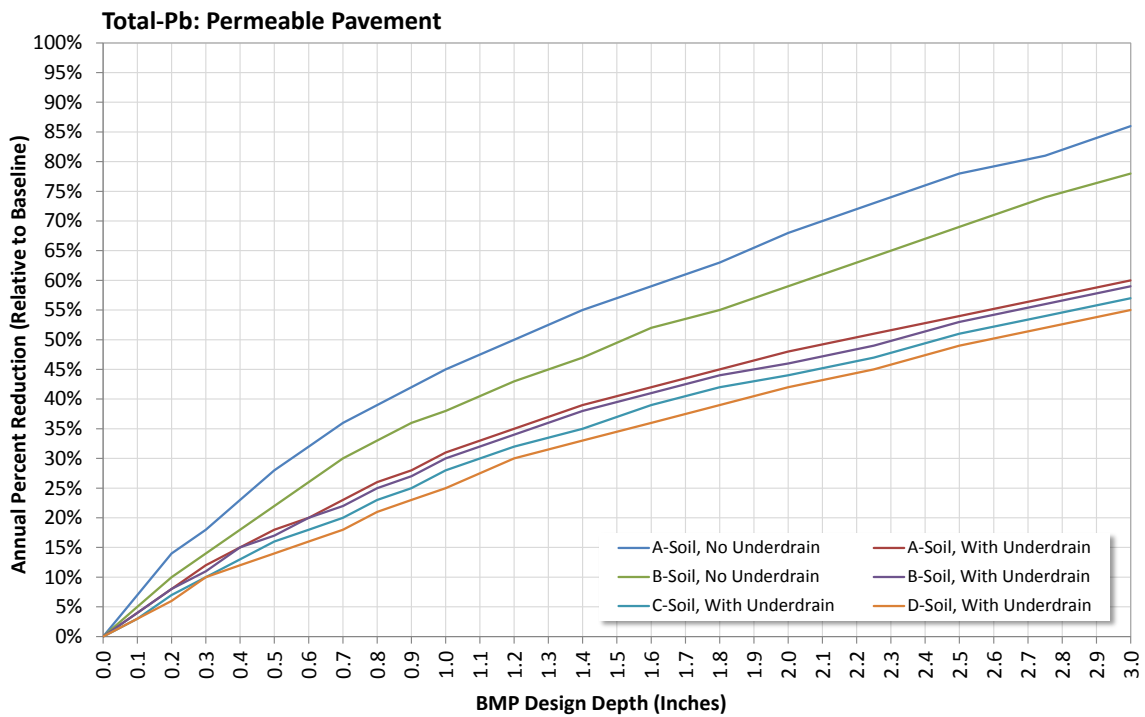
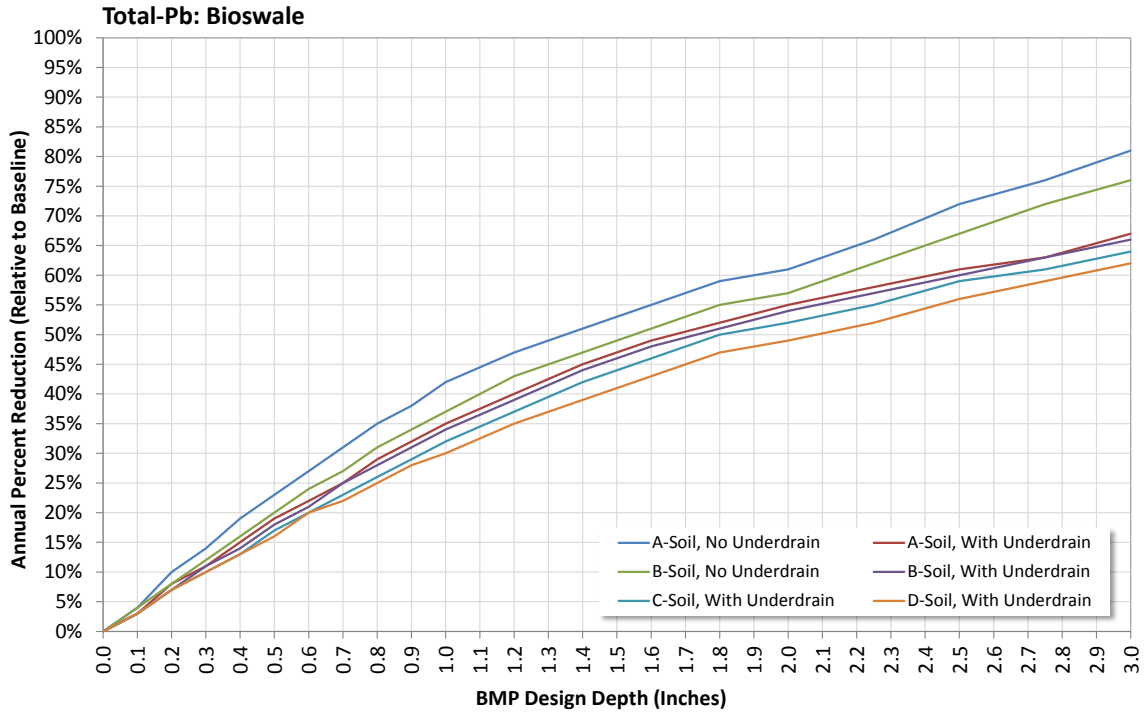
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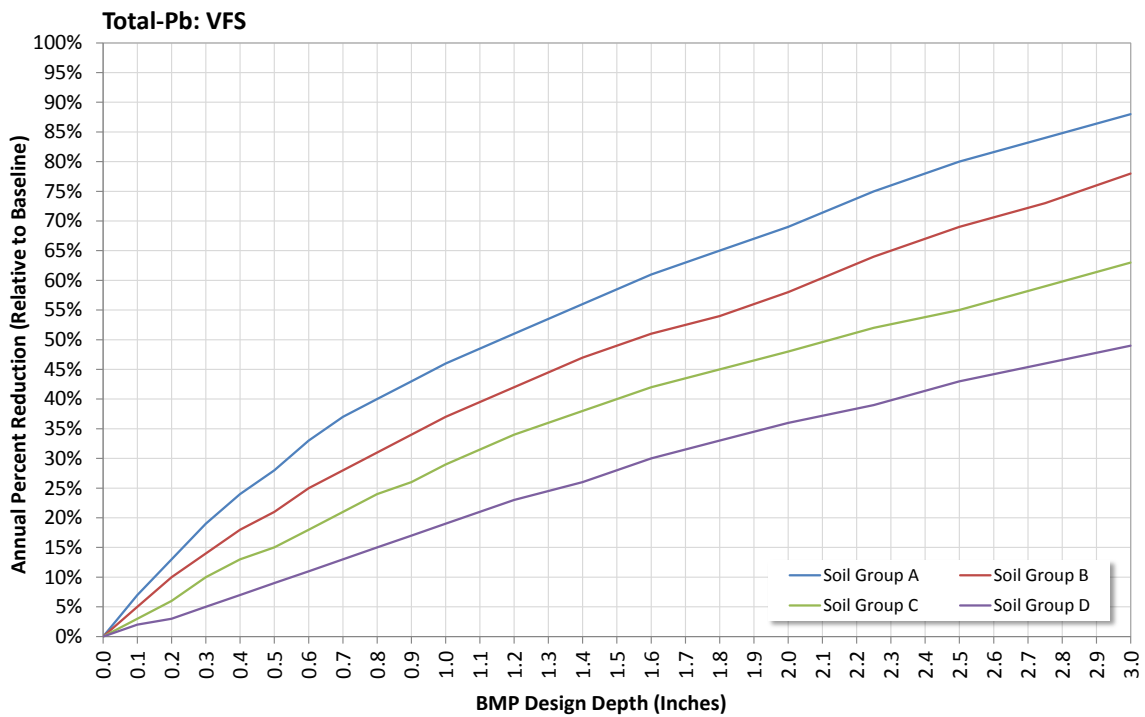
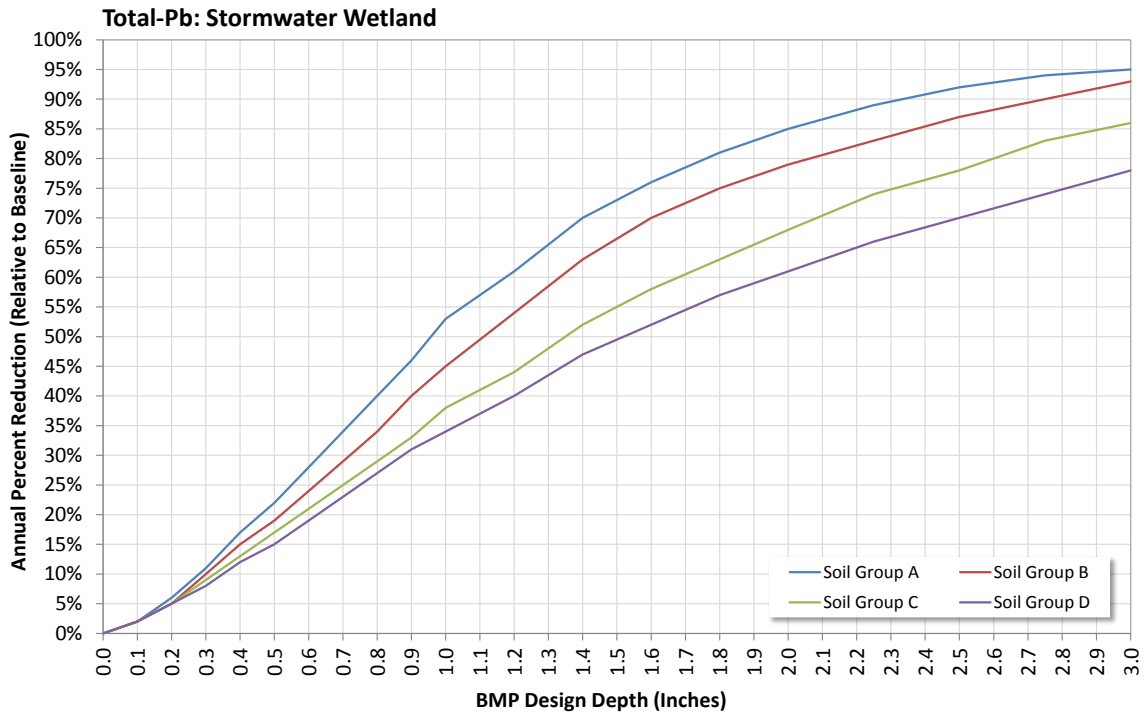
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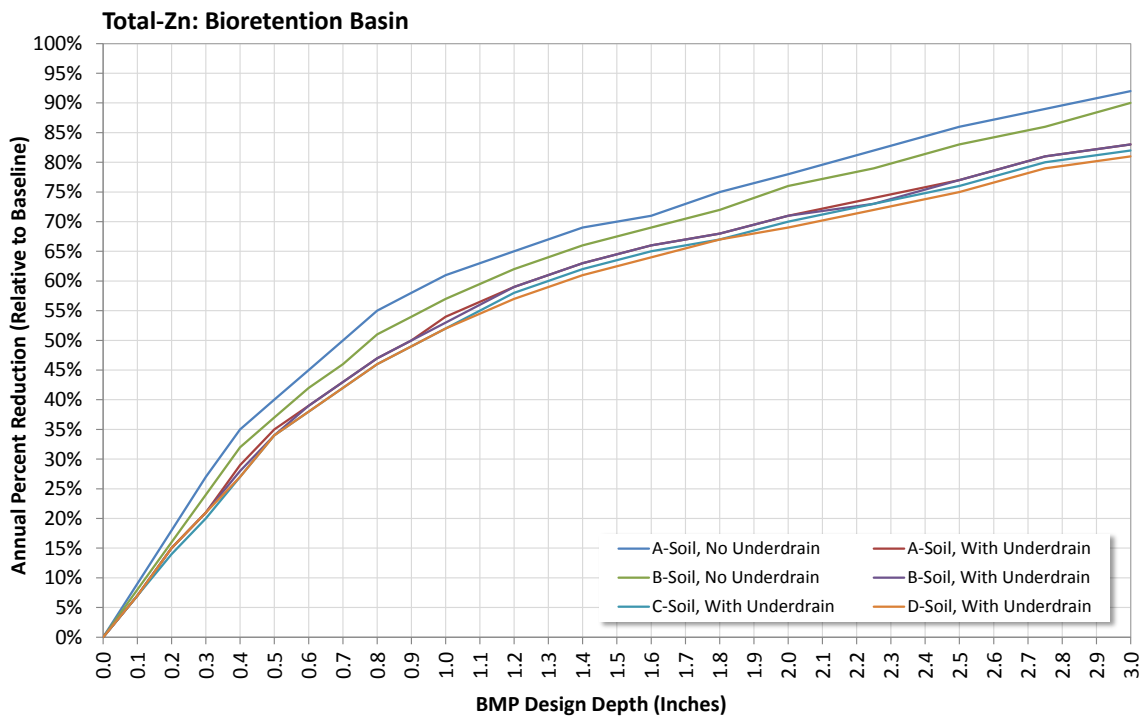
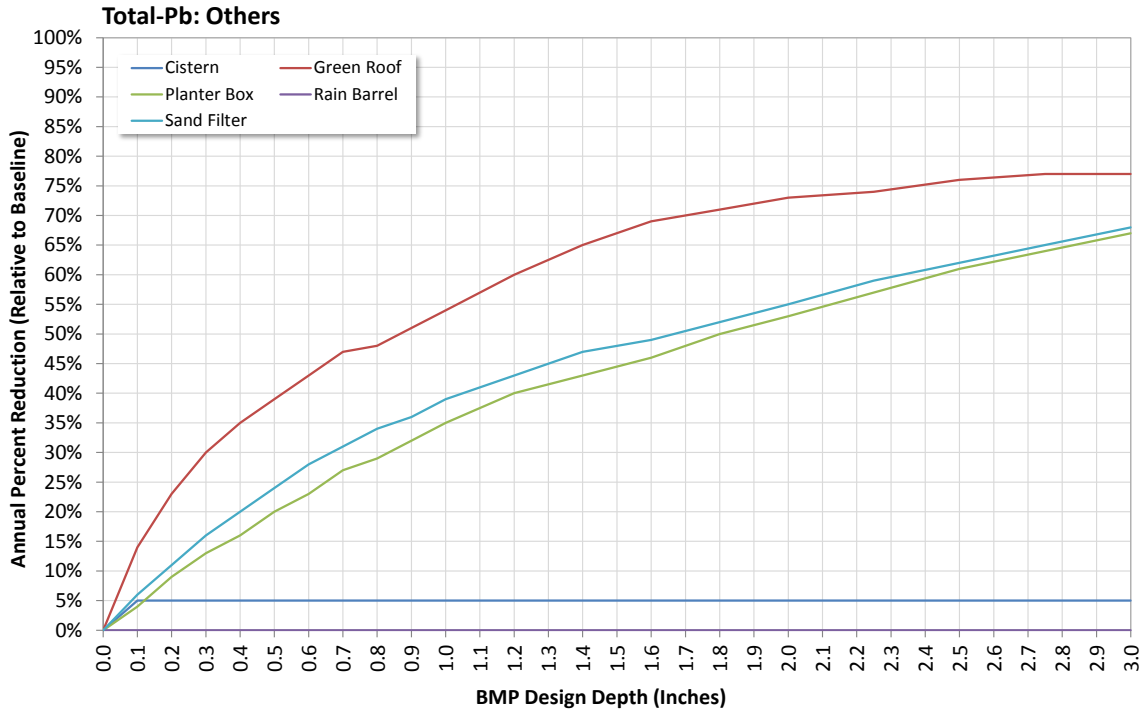
Appendix A.3 BMP Performance Curves



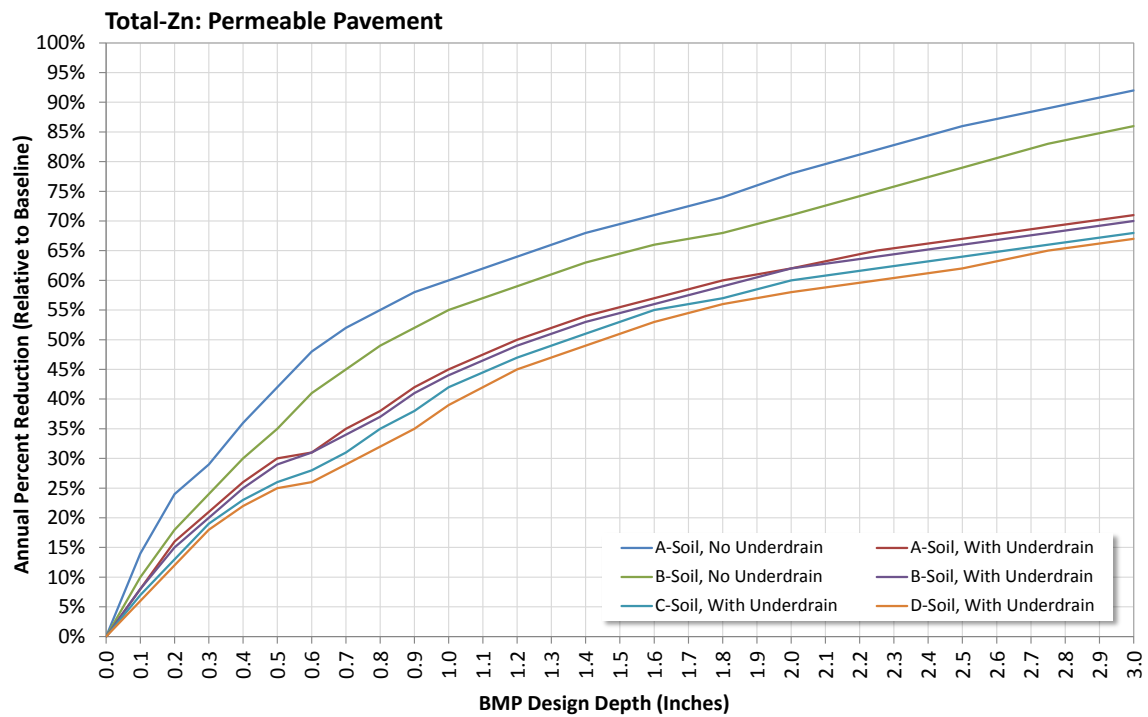
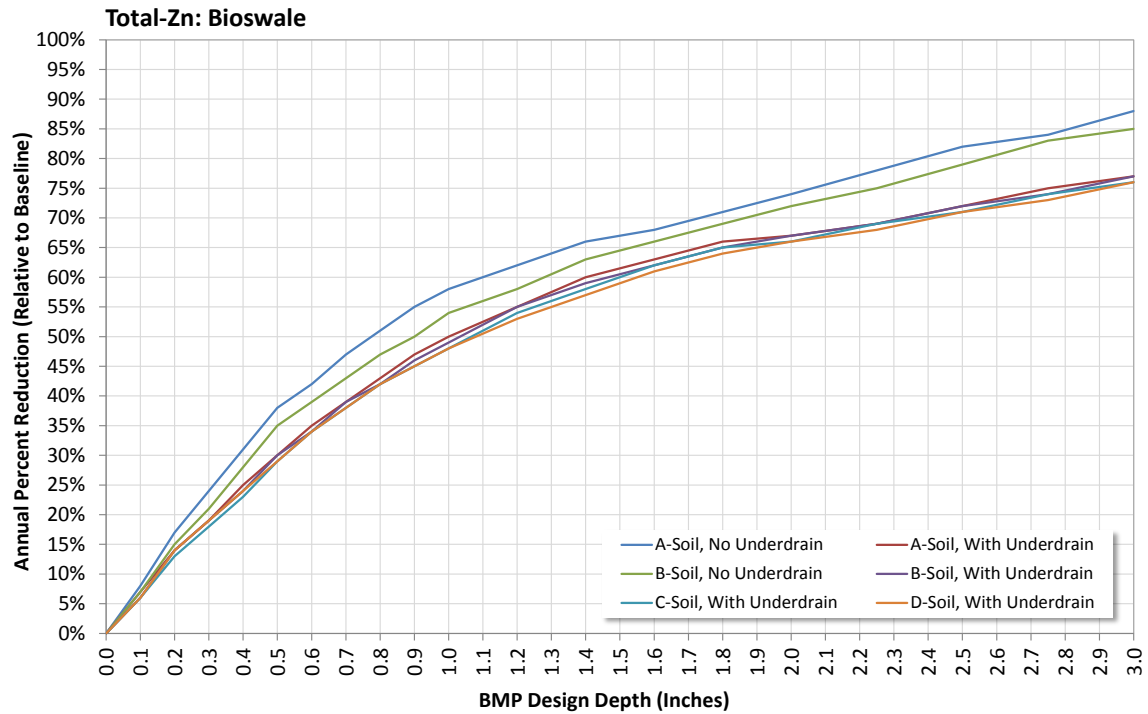
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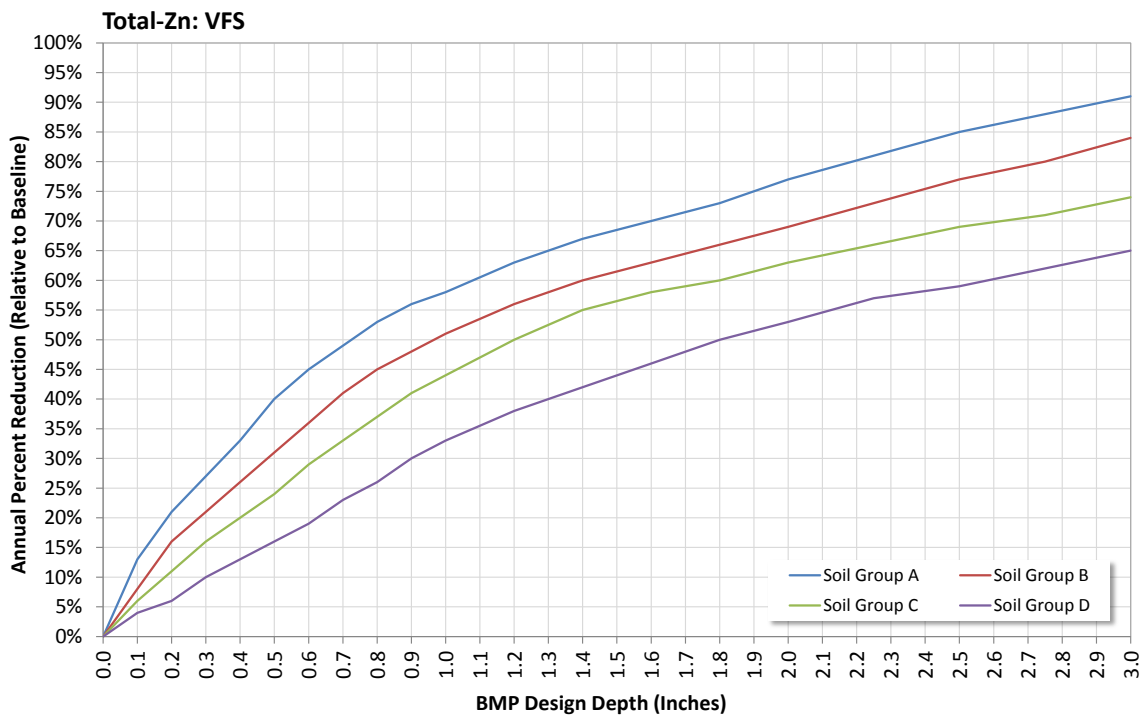
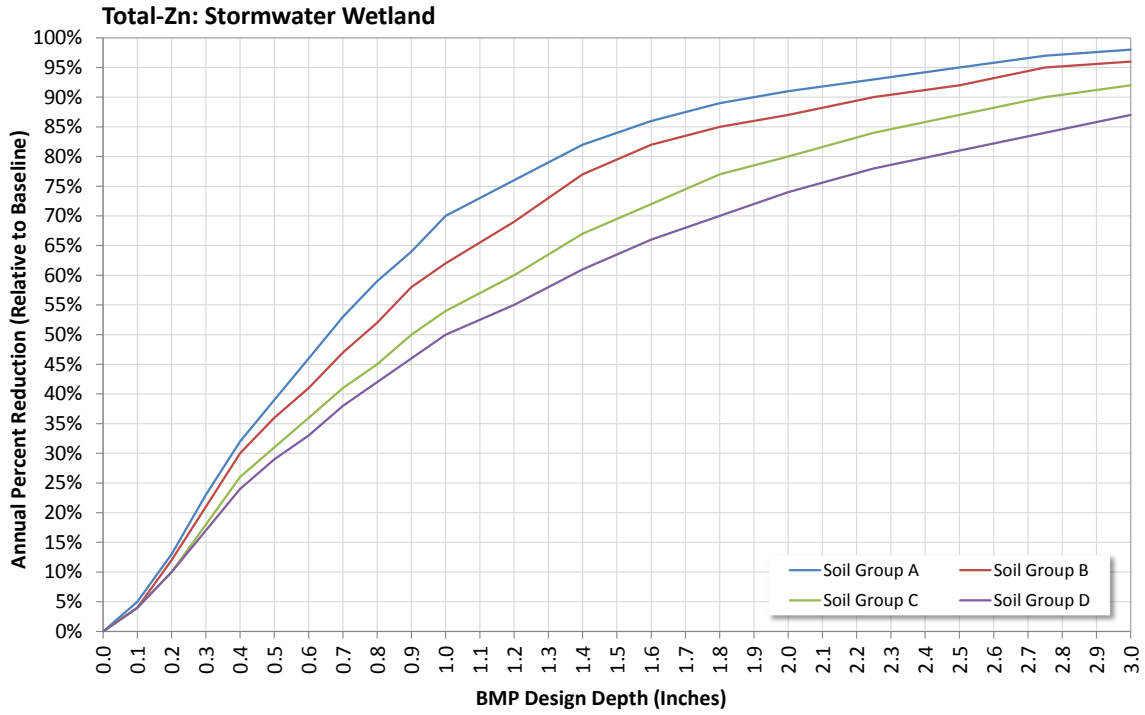
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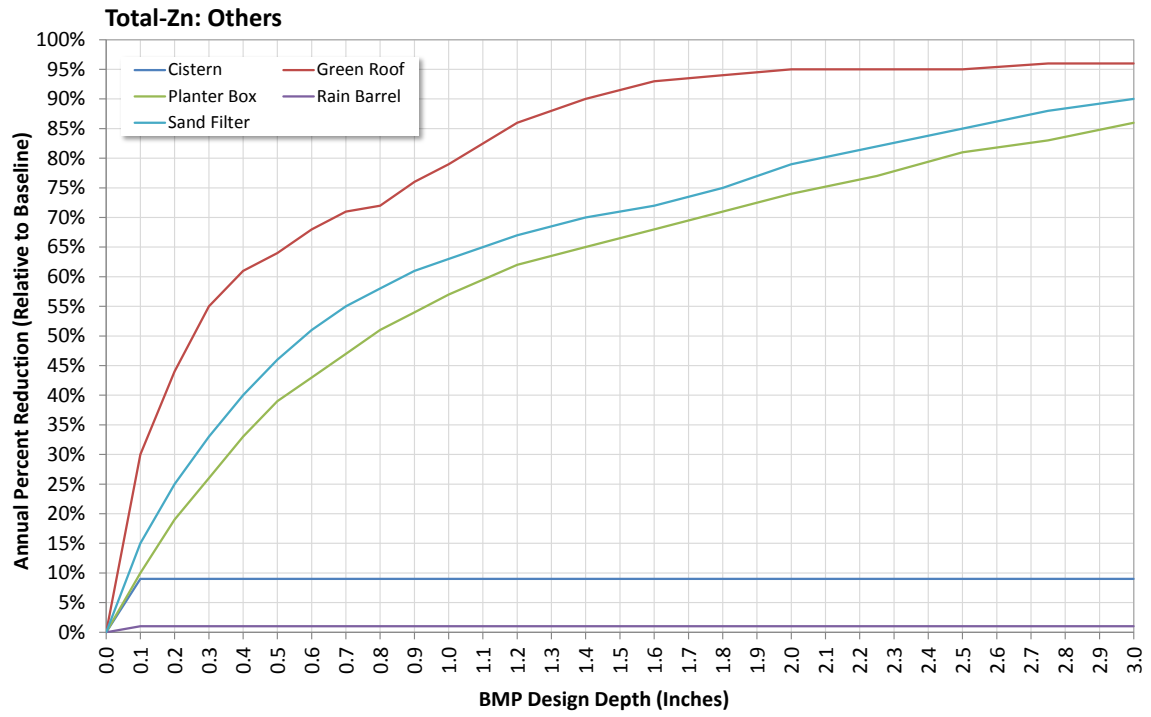
Appendix A.3 BMP Performance Curves



Appendix A.3 BMP Performance Curves



Appendix A.3 BMP Performance Curves



A.4 BMP Sizing

A.4.1 Volume-based Method 1

Two runoff volume calculation methods are used throughout the region and are adopted in this analysis. These are the Rational Method application for runoff volume estimation described in Section 6 of *Complying with the Edwards Aquifer Rules—Technical Guidance on Best Management Practices* (TCEQ 2005), and the Natural Resources Conservation Service (NRCS) hydrologic method described in the *San Antonio River Basin Regional Modeling Standards for Hydrology and Hydraulic Modeling* (SARA undated). As the Rational Method is recommended for watersheds less than 200 acres in area, that is the approach that is evaluated here. Local regulations may require the use of the NRCS or other rainfall-runoff analysis methods to calculate volumes or flow rates. In those cases, standard hydrologic software such as HEC-HMS can be utilized.

The Rational Method is implemented as follows:

$$WQV = C * \left(\frac{P_x}{12}\right) * A \quad \text{[Equation 1]}$$

Where:

WQV = BMP water quality storage volume (ft³),

C = runoff coefficient,

P_x = rainfall depth (determined in [Section A.2](#) or alternative from [A.1](#)),

A = watershed area draining to the BMP (ft²), and

$$C = C_i * (\%Imp) + C_p * (1 - \%Imp) \quad \text{[Equation 2]}$$

The value of C_i can be set to 0.95 to 1.0 depending on slope and roughness or may be calculated as a composite value for watersheds with multiple impervious cover types. Lower values would be appropriate for flat asphalt parking lots and higher values for metal, sloped roof buildings. The parameter C_p (pervious areas) will vary by hydrologic soil group (HSG) and land use type. In developed areas, the primary pervious areas are either undisturbed woods/brush or maintained lawns. Table A–3 lists runoff coefficients by HSG that are appropriate for use in the San Antonio River Basin and can be translated to curve numbers when evaluating BMP practices in watersheds over 200 acres.

Table A-3. Runoff coefficients for open space areas by hydrologic soil group

Hydrologic Soil Group	Woods, no grazing	Pasture (lawns)
A	0.06	0.10
B	0.13	0.20
C	0.16	0.25
D	0.20	0.30

A.4.2 Volume-based Method 2

Volume-based method 2 is described in Section 3.3 of the TGM (TCEQ 2005) and was developed to achieve TSS reduction targets by treating a percent of the annual rainfall volume. The calculation approach is applicable to LID design since it results in a capture volume based on watershed area. The method is implemented as:

$$WQV = \text{Rainfall Depth (in)} * \frac{\text{Runoff Coefficient}}{12} * \text{Area(ft}^2) * 1.2 \quad [\text{Equation 3}]$$

The runoff coefficient is estimated from Figure A-5 or calculated from

$$\text{Runoff Coefficient} = 1.72 * \%Imp^3 - 1.97 * \%Imp^2 + 1.23 * \%Imp + 0.02 \quad [\text{Equation 4}]$$

the rainfall depth is determined from Table A-4, and the area is the total watershed draining to the BMP in square feet. The storage factor 1.2 is provided to account for stored sediment that would reduce volume in between maintenance cycles.

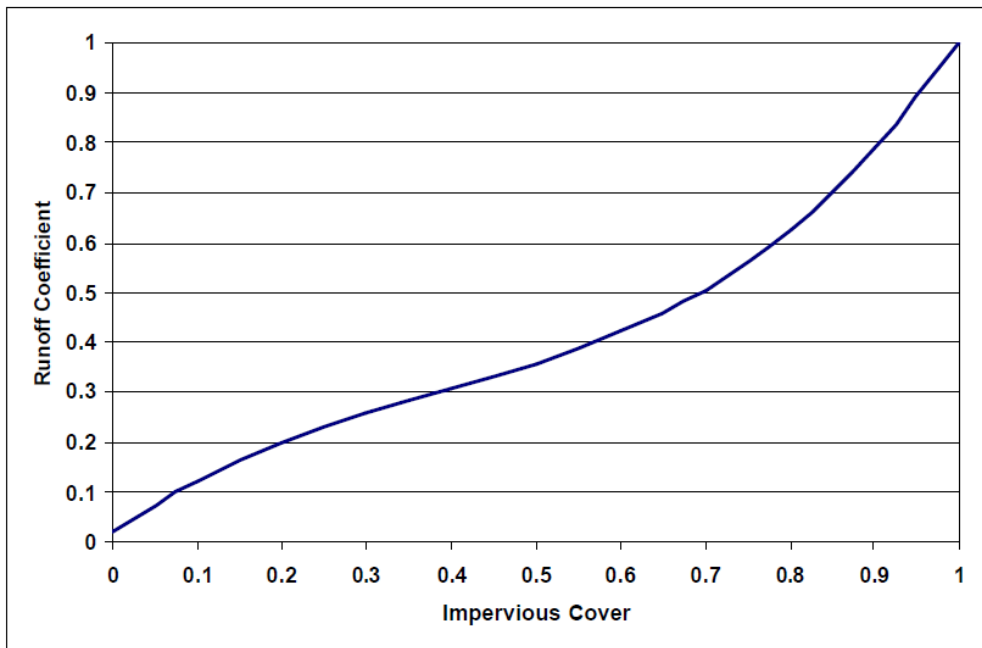


Figure A-5. Relationship between runoff coefficient and impervious cover (Figure 3-12 from TCEQ 2005)

Table A-4. Relationship between fraction of annual rainfall and rainfall depth (in)

(Table 3-5 from TCEQ 2005)

F	Rainfall Depth	F	Rainfall Depth	F	Rainfall Depth	F	Rainfall Depth
1.00	4.00	0.80	1.08	0.60	0.58	0.40	0.29
0.99	3.66	0.79	1.04	0.59	0.56	0.39	0.28
0.98	3.33	0.78	1.00	0.58	0.54	0.38	0.27
0.97	3.00	0.77	0.97	0.57	0.52	0.37	0.25
0.96	2.80	0.76	0.94	0.56	0.50	0.36	0.24
0.95	2.60	0.75	0.92	0.55	0.49	0.35	0.23
0.94	2.40	0.74	0.89	0.54	0.47	0.34	0.23
0.93	2.20	0.73	0.86	0.53	0.46	0.33	0.22
0.92	2.00	0.72	0.83	0.52	0.45	0.32	0.21
0.91	1.80	0.71	0.80	0.51	0.44	0.31	0.20
0.90	1.70	0.70	0.78	0.50	0.42	0.30	0.19
0.89	1.60	0.69	0.75	0.49	0.41	0.29	0.18
0.88	1.50	0.68	0.73	0.48	0.40	0.28	0.18
0.87	1.44	0.67	0.71	0.47	0.38	0.27	0.17
0.86	1.38	0.66	0.69	0.46	0.37	0.26	0.16
0.85	1.32	0.65	0.67	0.45	0.36	0.25	0.15
0.84	1.26	0.64	0.66	0.44	0.34		
0.83	1.20	0.63	0.64	0.43	0.33		
0.82	1.16	0.62	0.62	0.42	0.32		
0.81	1.12	0.61	0.60	0.41	0.31		
0.80	1.08	0.60	0.58	0.40	0.29		

A.5 Flow-Based Control Practices

Similar to the volume based control methods, two regionally appropriate methods are available to calculate flow-based sizing criteria for infiltrating, filtering, or treating:

1. The maximum flow rate of runoff produced from a rainfall intensity of 1.1 inch of rainfall per hour for each hour of a storm event (TCEQ 2005). Local rainfall analysis by TCEQ indicates 90 percent of the annual rainfall occurs at intensities below this level:

or

2. The maximum flow rate of runoff produced by the regulatory percentile hourly rainfall intensity, as determined from the local historical rainfall record, multiplied by a factor of two.

Both methods describe how to apply the design rainfall intensity for flow-based control practices (i.e., applying a uniform 1.1 inches per hour intensity or applying the regulatory percentile hourly rainfall intensity after multiplying by 2 as a safety factor).

A.5.1 Flow-based Method 1

The water quality flow (WQF, cfs) is calculated as

$$WQF = C * 1.1 * A, \quad \text{[Equation 5]}$$

where C is the rational method coefficient, as described above in [Section A.3](#), 1.1 in/hr is the rainfall intensity from the TCEQ's Edwards Aquifer compliance design manual, and A is the drainage area in square feet.

A.5.2 Flow-based Method 2

Flow-based method 2 is similar to method 1, except that the flow is based on the regulatory percentile peak intensity value from a local rainfall analysis (i), multiplied by a safety factor:

$$WQF = C * (i * 2) * A \quad \text{[Equation 6]}$$

The intensity should be calculated from rainfall data that covers at least 30 years of automated 5 to 15 minute automated recording gage data. Alternatively, hourly rainfall estimates could be used for areas with sparse gage data.

A.6 References

SARA (San Antonio River Authority). Undated. San Antonio River Basin Regional Modeling Standards for Hydrology and Hydraulic Modeling.

TCEQ (Texas Commission on Environmental Quality). 2005. *Complying with the Edwards Aquifer Rules—Technical Guidance on Best Management Practices*. RG-348 (Revised) with Addendum. Texas Commission on Environmental Quality, Austin, TX
<http://www.tceq.texas.gov/field/eapp>.

Appendix A.6 References

Example Problem

A property owner has a 5-acre, 75-percent-impervious commercial tract that discharges to a stream that is impaired for bacteria. The local municipality's stormwater management plan requires a 60 percent bacteria reduction for commercial properties in their jurisdiction. The site has surface parking and typical landscaping for the area, but the onsite soil is classified as low permeability clay (HSG D). You have evaluated the site and determined that bioretention within existing landscape areas is the most cost effective solution. Your city adopted the BMP curves in A.2 to calculate the required water quality volume. Determine the required volume to submit in support of your building permit.

Solution:

Bioretention is a volume based BMP that can be sized using Volume Based Method 1 (A.4.1) and the Rational Method equation (Equation 1)

$$WQV = C * \left(\frac{P_x}{12}\right) * A$$

The composite runoff coefficient is calculated from $C = C_i * (\%Imp) + C_p * (1 - \%Imp)$ (Equation 2) using a C_p of 0.30 (HSG D) from Table A-3 and C_i of 0.97 to reflect a mix of impervious surfaces and rooftops.

$$C = 0.97 * 0.75 + 0.3 * (1 - 0.75) = 0.8025$$

The rainfall depth is selected from the top figure on page A-12. Starting on the y-axis (annual percent reduction) at 60 percent and reading across to the right until intersecting the orange line (D soil, with underdrain). Follow the vertical lines down and read the BMP design depth of 1.2 inches from the x-axis.

Inserting these values into the equation produces

$$WQV = 0.8025 * \left(\frac{1.2}{12}\right) * 5 \text{ ac} * 43,560 \text{ ft}^2 = 17,478.5 \text{ ft}^3$$

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B.1 Bioretention Areas



Rendering showing how roadside bioretention can be retrofit into the right-of-way to intercept street runoff through curb cuts, Broadway Street, Witte Museum, San Antonio, Texas. Source: Bender Wells Clark Design

B.1.1 Volume Management

The design of a bioretention area can be broken down to a nine-step process. Table B-1-1 summarizes the steps, which are described in greater detail in this chapter.

Table B-1-1. Iterative design step process

Design step		Design component/ consideration	General specification
1	Determine BMP Treatment Volume (B-9)	Use Appendix A	
2	BMP Siting (B-9)	Based on available space and maintenance access, incorporate into parking lot islands, medians, and perimeter; install along the roadway right-of-way; incorporate as landscaped areas throughout the property; or dedicate space for larger, centralized bioretention areas	
3	Determine BMP Function and Configuration (B-10)	Impermeable liner	If non-infiltrating (per geotechnical investigation), use an impermeable clay layer, geomembrane liner, and concrete (as described in Common Design Elements)
		Lateral hydraulic restriction barriers	Use concrete or geomembrane to restrict lateral flows to adjacent subgrades, foundations, or utilities.
		Underdrain (required if subsoil infiltration rate is less than 0.5 in/hr)	Schedule 40 PVC pipe with perforations (slots or holes) every 6 inches. 4-inch diameter lateral pipes should join a 6-inch collector pipe, which conveys drainage to the downstream storm network. Provide cleanout ports/observation wells for each underdrain pipe at spacing consistent with local regulations. See Common Design Elements
		Internal water storage (IWS)	If using underdrain and infiltration, elevate the outlet to create a sump for additional moisture retention to promote plant survival and enhanced treatment. Top of IWS should be greater than 18 inches below soil surface.
		No underdrain	If design is fully infiltrating, ensure that subgrade compaction is minimized.
4	Size the System (B-14)	Temporary ponding depth	6-18 inches (6-12 inches near schools or in residential areas); average ponding depth of 9 inches is recommended
		Soil media depth	2-4 feet (deeper for better pollutant removal, hydrologic benefits, and deeper rooting depths)
		Surface area	Find surface area required to store treatment volume within temporary ponding depth, soil media depth, and gravel drainage layer depth (media porosity \approx 0.35 and gravel porosity \approx 0.4)
5	Specify Soil Media (B-16)	Composition and texture	85-88% sand, 8-12% fines, 2-5% plant-derived organic matter (animal wastes or by-products should not be applied)
		Permeability	1-6 in/hr infiltration rate (1-2 in/hr recommended)
		Chemical composition	Total phosphorus < 15 ppm, pH 6-8, CEC > 5 meq/100 g soil
		Drainage layer	Separate soil media from underdrain layer with 2 to 4 inches of washed sand, followed by 2 inches of choking stone (ASTM No. 8) over a 1.5-foot envelope of ASTM No. 57 stone.
6		Inlet	Provide stabilized inlets (see Common Design Elements)

Design step		Design component/consideration	General specification
	Design Inlet and Pretreatment (B-17)	Pretreatment	Install rock armored forebay (concentrated flow), gravel fringe and vegetated filter strip (sheet flow), or vegetated swale
7	Select and Design Overflow/Bypass Method (B-21)	Outlet configuration	Online: All runoff is routed through system—install an elevated overflow structure or weir at the elevation of maximum ponding Offline: Only treated volume is diverted to system—install a diversion structure or allow bypass of high flows (see Diversion Structures for details)
		Peak flow mitigation	Provide additional detention storage and size an appropriate non-clogging orifice or weir to dewater detention volume
8	Select Mulch and Vegetation (B-24)	Mulch	Dimensional chipped hardwood or triple shredded, well-aged hardwood mulch 3 inches deep.
		Vegetation	See Plant List (Appendix E)
9	Design for Multi-Use Benefits (B-27)	Include features to enhance habitat, aesthetics, public education, and shade.	

Step 1. Determine BMP Treatment Volume

The bioretention area must be sized to fully capture the desired or required design storm volume and filter it through the soil media. Relevant regulatory requirements are summarized in Chapter 2. Surface storage (in the ponding area) and soil pore space (in the plant rooting zone and the underlying media and gravel drainage layers) provide capacity for the design storm volume retention. Appendix A outlines methods for determining design runoff depths associated with a range of annual treatment efficiencies. Once the design runoff depth is determined (on the basis of the desired level of treatment), a runoff volume can be determined for the contributing watershed using this depth and the methods outlined in Appendix A, *San Antonio Unified Development Code*, or *San Antonio River Basin Regional Modeling Standards for Hydrology and Hydraulic Modeling*.

Peak flow rates for the design storm should also be calculated, using the methods outlined in Appendix A so that the inlet and pretreatment can be accordingly sized and flow attenuation can be considered

Step 2. BMP Siting

Bioretention is a versatile stormwater BMP that can effectively reduce pollutants and can be integrated into site plans with various configurations and components. Stormwater treatment should be considered as an integral component and incorporated in the site design and layout from conception. Many times, determining how the bioretention area will be included in the site design is a critical and required first step. How the water is routed to the bioretention area and the available space will be key components in determining how the bioretention area is configured. Site assessment, planning, and site design are discussed in detail in Section 1.5. The following is a list of settings where bioretention can be incorporated to meet more than one project-level or watershed-scale objective:

- Landscaped parking lot islands
- Common landscaped areas

Appendix B.1 Bioretention Areas

- In parks and along open space edges
- Within rights-of-way along roads

How the bioretention area is configured will determine the required components. Bioretention areas can serve the dual purpose of stormwater management and landscape design and can significantly enhance the aesthetics of a site. Figure B-1-1 shows an example of the components of a typical bioretention area. When siting bioretention, consideration must always be given to providing access for routine, intermittent, and rehabilitative maintenance activities.

Bioretention areas can be combined with other BMPs to form a treatment train that can provide enhanced water quality treatment and reductions in runoff volume and rate. For example, runoff can be collected from a roadway in a vegetated swale that then flows to a bioretention area. Both facilities can be reduced in size on the basis of demonstrated performance for meeting the stormwater runoff requirements as outlined in Chapter 2 and addressing targeted pollutants of concern.

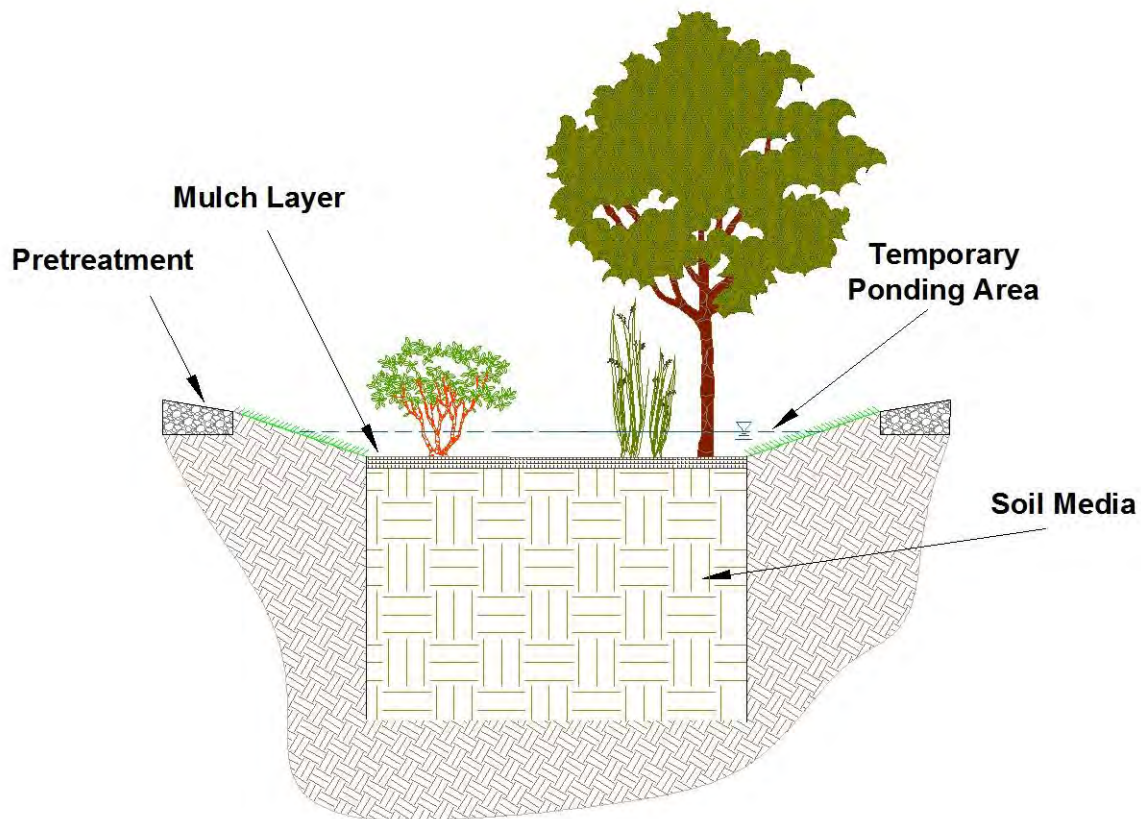


Figure B-1-1. Basic bioretention components

Step 3. Determine BMP Function and Configuration

Intended bioretention functions and configuration must be characterized early in the design process. Infiltration through native soils provides the greatest treatment potential and lowest cost. Where infiltration is limited, a high level of treatment can still be provided by filtering stormwater through an engineered soil media. The following subsections describe the necessary steps to determine if the bioretention area will safely function as an infiltration or filtration BMP.

Peak flow rates for the design storm should also be calculated, using the methods outlined in Appendix A so that the inlet and pretreatment can be accordingly sized and flow attenuation can be considered.

Geotechnical Investigation

A licensed soil scientist or geotechnical engineer should conduct a geotechnical investigation before the BMP design. The investigator should determine the infiltration rate of the soils at the potential subgrade of the bioretention cell, the depth to the seasonally high groundwater table, presence of expansive clay minerals, and whether there is a risk of sinkhole formation. Site location with respect to aquifer recharge zones, steep slopes, water supply wells, and septic drain fields must also be assessed. For more details, see [Common Design Elements](#).

Determine if Underdrains and Impermeable Liners are Needed

Underdrains will be required if a bioretention cell is lined, adjacent to a steep slope, or if the subsoil infiltration rate (as determined during the geotechnical analysis) is less than 0.5 inch per hour (in/hr). Use Table B-1-2 to determine if a bioretention area requires an impermeable liner or underdrain. For more information concerning the use of fully lined bioretention, see [Planter Boxes](#)

Table B-1-2. Decision table for determining underdrain and impermeable liner requirements

Impermeable liners must be used if...	Underdrains must be used if...
<ul style="list-style-type: none"> • Site is in Edwards Aquifer Recharge Zone, Contributing Zone, or Transition Zone (Barrett 2005) • Soil contamination is expected or present • Karst geology presents risk of sinkhole formation • Runoff could unintentionally be received from a stormwater hotspot • Site is within 100 feet of a water supply well or septic drain field • Site is within 10 feet of a structure/foundation • Infiltrated water could interfere with utilities 	<ul style="list-style-type: none"> • An impermeable liner is needed • Infiltration rate of underlying soils is less than 0.5 in/hr • Site is within 50 feet of a steep, sensitive slope (as determined in the geotechnical analysis—see Common Design Elements)

Determine if Lateral Hydraulic Restriction Barriers are Needed

When bioretention areas are near sensitive infrastructure such as pavement subgrades or buried utilities, hydraulic restriction barriers are often required to prevent lateral seepage. Hydraulic restriction barriers are often installed the full depth of excavation, but occasionally they are keyed in to greater depths to ensure vertical, deep infiltration; the geotechnical investigator should determine the required extent of hydraulic restriction barriers. [Common Design Elements](#) provides specific details concerning lateral hydraulic restriction barrier design.

Design Underdrain and Internal Water Storage

The underdrain configuration greatly affects the gradient for water movement through a bioretention cell, and the hydrologic and water quality performance. Conventionally drained cells feature an underdrain that freely drains and outlets at the elevation of the subgrade (Figure B-1-2).

Appendix B.1 Bioretention Areas

Infiltration and pollutant load reduction can be further enhanced by upturning the underdrain to create a sump (Brown and Hunt 2011a). This internal water storage (IWS) zone enhances exfiltration into underlying soils while maintaining aerobic soil conditions in the plant rooting zone. It is most convenient to upturn the underdrain in the outlet structure using a tee-connection; this allows easy access to the underdrain for inspection and maintenance (Figure B-1-3 and Figure B-1-4). IWS can be used in conjunction with an impermeable liner, but volume calculations must account for the possibility of prolonged saturation in the lower media. Inclusion of IWS is recommended in arid and semi-arid regions (such as San Antonio) to maintain soil moisture for plant health (Li et al. 2010; Barrett et al. 2012; Houdeshel et al. 2012). To provide an aerobic root zone and to reduce mobilization of previously captured pollutants, the IWS zone should be at least 18 inches below the surface (Hunt et al. 2012). For recommended underdrain specifications, see [Common Design Elements](#).

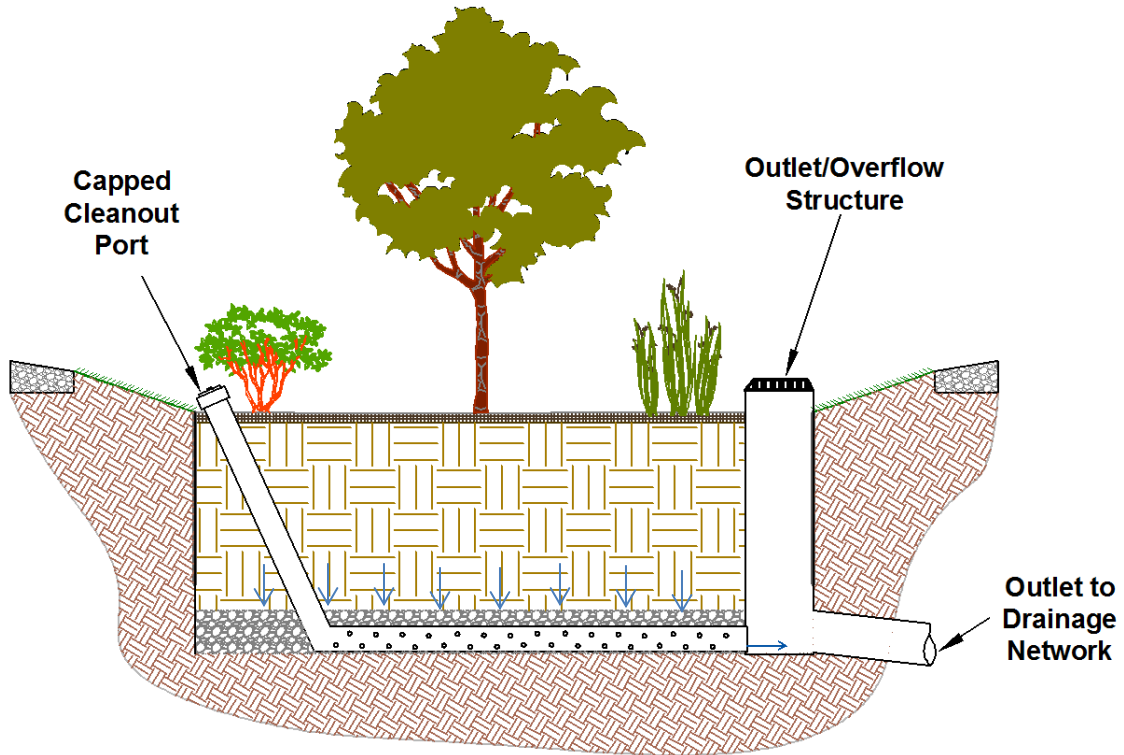


Figure B-1-2. Conventionally drained bioretention cross section showing underdrain

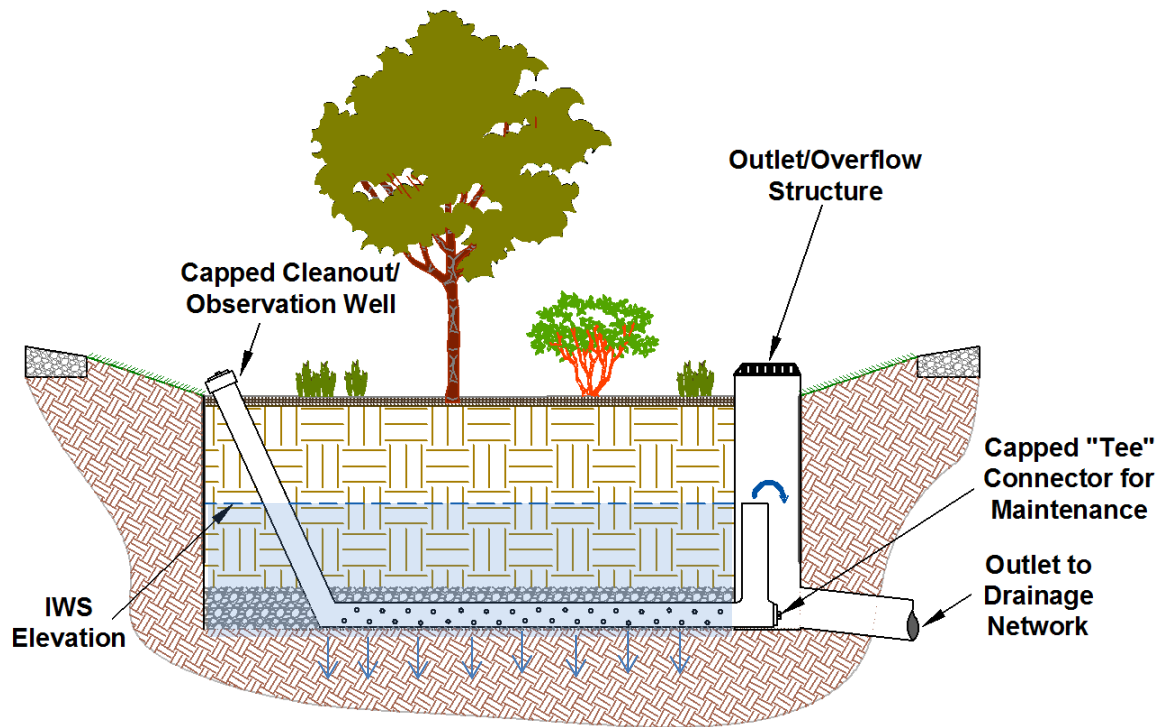


Figure B-1-3. Bioretention cell profile with IWS drainage configuration



Figure B-1-4. Upturned underdrains inside bioretention outlet structures create IWS in soil media to improve infiltration, water quality, and plant health, North Carolina. Source: Tetra Tech

Step 4. Size the System

The required water quality treatment volume is determined in Appendix A. Vertical dimensions should be selected on the basis of pollutants of concern and site constraints before calculating the BMP footprint. The following subsections provide guidance on sizing the surface ponding depth, media depth, and footprint of bioretention areas.

Surface Ponding Depth

Bioretention areas should have a maximum ponding depth of 12 inches but can temporarily detain runoff to a depth of 18 inches if designed for peak flow mitigation (Heasom et al. 2006; more detail concerning peak flow mitigation is provided in [Step 7](#)). Although research has demonstrated excellent performance from bioretention areas with deeper ponding depths (more than 12 inches), greater care must be taken to select vegetation that can withstand both inundation and drought, and public safety must be considered (Hunt et al. 2012). Maximum ponding depth might also be limited by vertical constraints of the site, including the elevation of existing downstream storm drain networks. For these reasons, a 9-inch average ponding depth is typically preferred. Local freeboard requirements (typically 1.0 foot for online systems and 0.5 foot for offline systems) should also be considered when selecting a ponding depth (Barrett 2005).

Soil Media Depth

Soil media depth should be optimized to meet hydrologic and water quality goals but should have a minimum depth of 2 feet (3 feet is recommended for systems with IWS; Hunt et al. 2012). The soil media provides a beneficial root zone for the chosen plant palette and adequate water storage for the water quality volume. A deeper soil media depth will provide a smaller surface area footprint by allowing more storage in the pore spaces and subsequently more evapotranspiration of stormwater by plants.

Table B-1-3 summarizes the minimum recommended media depths for targeted removal of various pollutants (as detailed in Chapter 3). Considering the target pollutant, the depth of the media in a bioretention cell should be between 2 and 4 feet. That range reflects the fact that most of the pollutant removal occurs within the first 2 feet of soil, and excavations deeper than 4 feet become

more expensive. The depth should accommodate the desired vegetation (shrubs or trees). If the minimum depth of 2 feet is used over restrictive underlying soils or an impermeable liner, only shallow-rooted vegetation should be planted; grassed bioretention cells can be as shallow as 2 feet. Bioretention facilities where shrubs or trees are planted could be as shallow as 3 feet unless a soil test indicates that shallower depths will support plant health. Media depths greater than 3 feet might be desired for additional pollutant removal, thermal load reduction, and hydrologic benefits, but 3 feet is typically sufficient. If large trees are to be planted in deep fill media, care should be taken to prevent overturning in high winds. Stakes and guy lines might be required to stabilize the trees during establishment.

Table B-1-3. Minimum bioretention depth to treat pollutants of concern (Hunter et al. 2012)

Pollutant of concern	Removal zone	Recommended depth
Sediment	Surface, top 2-8 inches	2 feet
Total nitrogen	At depth in IWS layer (>2 feet)	3 feet
Total phosphorus	Top 1-2 feet	2 feet
Pathogens	Top 1-2 feet	2 feet
Metals	Top 1-2 feet	2 feet
Oil and grease	Surface	2 feet
Temperature	At depth	4 feet

Size Surface Area

The footprint of the bioretention area should be calculated after the desired ponding depth and soil media depth have been selected. Bioretention areas should be sized to fully capture the treatment volume (from Appendix A) within the surface ponding zone and subsurface pore space. Available storage in the subsurface soil media and gravel drainage layer should be determined on the basis of the laboratory-measured porosity of materials that will be installed on-site; this information is typically available from suppliers or quarries. The porosity, n , of bioretention media can be estimated as 0.35, and the porosity of ASTM No. 57 gravel can be estimated as 0.40 for preliminary calculations (Brown et al. in press).

$$n = \frac{V_v}{V_T} \quad \text{[Equation B-1-1]}$$

where

n = porosity (volume/volume)

V_v = volume of void space

V_T = total volume

The equivalent storage depth for a unit bioretention cross section can be calculated as follows:

$$D_{eq} = (D_{surface}) + (n_{media} \times D_{media}) + (n_{gravel} \times D_{gravel}) \quad \text{[Equation B-1-2]}$$

Appendix B.1 Bioretention Areas

where

D_{eq} = equivalent depth of water stored in representative cross sectional of bioretention

$D_{surface}$ = average depth of temporary surface ponding (maximum 12 inches)

n_{media} = porosity of soil media

D_{media} = depth of soil media

n_{gravel} = porosity of gravel drainage layer

D_{gravel} = depth of gravel drainage layer

If the bioretention area is being used for peak flow mitigation, the detention storage depth (volume that will bypass the soil media) cannot be included in $D_{surface}$. More information is provided in [Step 7](#).

The treatment volume (V_{wq}) is divided by the equivalent depth (D_{eq}) to calculate the required bioretention footprint:

$$A = \frac{V_{wq}}{D_{eq}} \quad \text{[Equation B-1-3]}$$

where

A = required bioretention footprint (area)

V_{wq} = water quality treatment volume (determined in Appendix A)

D_{eq} = equivalent depth

Step 5. Specify Soil Media

Bioretention areas are intended to drain to below the surface in less than 24 hours but should be designed to drain in 12 hours or less as a safety factor. Typically the soil media is dewatered in less than 48 hours for plant health. If a gravel drainage layer is included beneath the bioretention area soil media, stored runoff in the drainage layer should drain in less than 72 hours. The soils must be allowed to dry out periodically to restore hydraulic capacity to receive flows from subsequent storms, maintain infiltration rates, maintain adequate soil oxygen levels for healthy soil biota and vegetation, and to provide proper soil conditions for biodegradation and retention of pollutants.

Organic matter is considered an additive to help vegetation initially establish and contributes to sorption of pollutants; however, organic materials will oxidize over time causing an increase in ponding that could adversely affect the performance of the bioretention area. Additionally, studies in Texas have demonstrated pollutant leaching when bioretention soils were amended with excessive compost (Li et al. 2010). Organic material should therefore be minimized (less than 5

percent of media volume) and consist of minimal plant-based materials. Organic amendments should *not* include any animal manure or by-products, which can export nutrients and pathogens.

High levels of phosphorus in the media have been identified as the main cause of bioretention areas exporting nutrients (Hunt and Lord 2006). All bioretention media should be analyzed for background levels of nutrients. All soil properties should be measured by a qualified soils laboratory with AASHTO, USACE, or State accreditation.

Soil media should meet the specifications listed in Table B-1-4. If the existing soils meet the criteria, it can be used as the soil media. If the existing soils do not meet the criteria, soils should be amended with the appropriate components or a substitute media must be used.

Table B-1-4. Bioretention soil media specifications (Hunter et al. 2012)

Parameter	Specification
Texture and Composition (by volume)	Soil media should consist of a loamy sand conforming to the following specifications: 85 to 88% washed coarse sand (concrete sand passing a one-quarter-inch sieve or thoroughly washed mortar sand passing a one-eighth-inch sieve) 8 to 12% fines passing a #270 sieve (8% fines typically yields an infiltration rate near 2 in/hr, whereas 12% fines yields an infiltration rate near 1 in/hr) 2 to 5% organic matter
Organic Matter Material	Aged bark fines, hardwood chips, leaf litter, or similar plant-derived, composted organic material screened to 3/8 in or less. Studies have also shown newspaper mulch to be an acceptable additive (Kim et al. 2003; Davis 2007). Organic matter should not include animal manure or by-products.
Infiltration Rates	0.5 to 6 in/hr (1-2 in/hr recommended for comprehensive pollutant treatment and hydrologic benefit; Hunt et al. 2012)
pH	6 to 8
Cation Exchange Capacity (CEC)	Greater than 5 milliequivalents (meq)/100 g soil
Phosphorus	Total phosphorus should not exceed 15 ppm

Step 6. Design Inlet and Pretreatment

Inlets must be designed to convey the design storm volume into the bioretention area while limiting ponding or flooding at the entrance to the bioretention area and protecting the interior of the bioretention area from damage. Take care during grading to ensure that the drainage area is properly sloped toward the bioretention area and that the inlet elevation is at least as high as the intended maximum ponding depth (for more information, see [Critical Construction Considerations](#)). In addition to inlet design, pretreatment is critical to remove coarse sediment and debris to prolong the functional life of the soil media. Several options are available depending on the configuration of the bioretention area and the drainage area characteristics.

Inlets

The way in which runoff is routed to the bioretention area will dictate the type of inlet. If sheet flow constitutes the source of runoff, curb cuts are typically used; design guidance for curb cuts is provided in the [Common Design Elements](#) section. If flows are concentrated, channels or conduit can be used to convey runoff to the bioretention area.

Appendix B.1 Bioretention Areas

Energy Dissipation and Pretreatment

Design of pretreatment measures will vary depending on the site layout. If sheet flow (such as parking lot runoff) is conveyed to the treatment area, the site must be graded in such a way that minimizes erosive conditions. Gravel fringes between pavement and grassed surfaces can help distribute flow and provide initial pretreatment. Gravel should consist of a 2-inch layer of ASTM No. 57 stone (underlain by filter fabric) extending 2 to 3 feet from the pavement edge, where space allows (Figure B-1-5). Filter strips should ideally be sodded and graded at 3:1 (horizontal:vertical) slopes or flatter. Any slopes that convey flow should be routinely inspected for rill erosion, which can contribute excessive sediment to the bioretention area and often represents the most common maintenance issue (Wardynski and Hunt 2012). Take care to prevent flow from concentrating between parking lot curb stops/blocks.



Figure B-1-5. Gravel fringe and vegetated filter strip pretreatment, Louisburg, North Carolina.
Source: North Carolina State University Department of Biological and Agricultural Engineering

Runoff can be routed to a bioretention area through a vegetated swale to pretreat incoming flows from impervious surfaces. Whenever concentrated flow is conveyed to the bioretention area (via channels or conduit) a rock-armored forebay should be used to dissipate energy and provide pretreatment of gross solids and sediment. Forebays should compose approximately 10 percent of the total bioretention area and should be designed to dewater between storm events to prevent vector hazards (Hunt and Lord 2006, Hunt et al 2007). Armored inlets can be used where space is limited (as shown in Figure B-1-6 and Figure B-1-7).

Bioretention areas that treat runoff from residential roofs or other *cleaner* (low sediment and debris yield) surfaces might not require pretreatment for trash or sediment but should include energy

dissipation to the extent practicable. Energy dissipation can be provided by upturning inflow pipes so that they bubble up diffusely onto a rock apron (Figure B-1-8); otherwise, baffles, blocks, or cobbles can be used to still high velocities. Flow velocities should not exceed 3 feet per second (ft/sec) for grassed surfaces and 1 ft/sec for mulched surfaces.



Figure B-1-6. Inlet and pretreatment provided by mortared cobble forebay and energy dissipater, Los Angeles, California. Source: Tetra Tech



Figure B-1-7. Inlets stabilized with mortared cobble, Los Angeles, California. Source: Tetra Tech



Figure B-1-8. Upturned inlet from rooftop bubbles up diffusely onto gravel pad, Chocowinity, North Carolina. Source: Tetra Tech

Step 7. Select and Design Overflow/Bypass Method

Two design configurations (offline or online) can be used for treating storms that are larger than the bioretention area is designed to store. If peak flow cannot be fully mitigated by the flow rate through the soil media, the outlet can be adapted to meter the rate of outflow.

Offline

An offline bioretention area (Figure B-1-9) can be designed such that stormwater bypasses the bioretention area once the capacity has been exceeded. A structure can also be designed that diverts into the bioretention area only the volume of stormwater for which the bioretention area is designed. For more information on diversion structures, see [Common Design Elements](#).

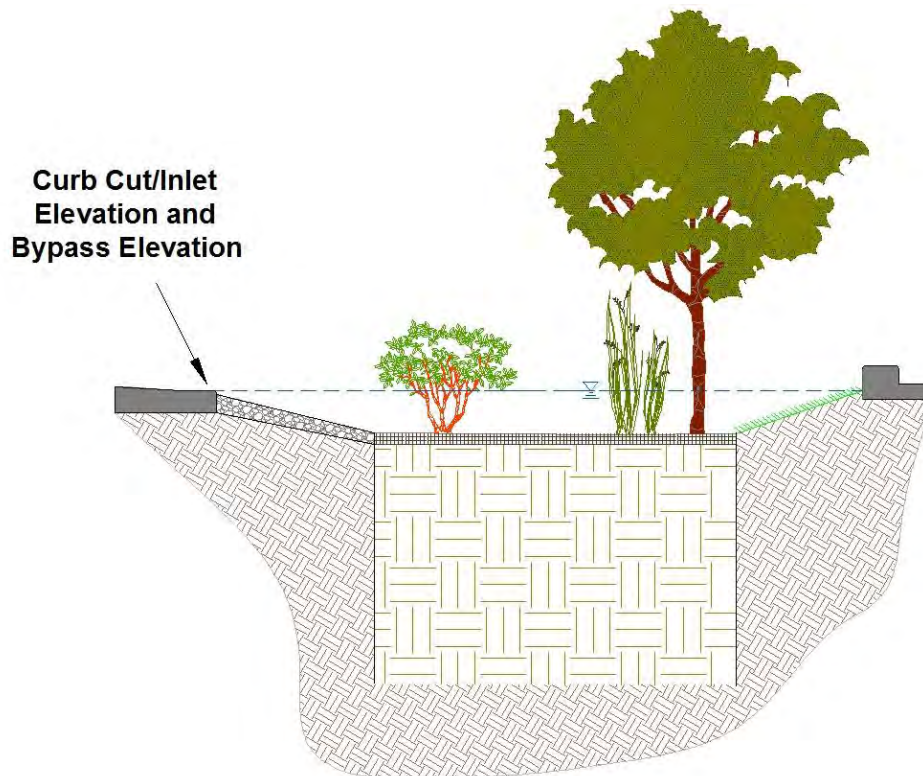


Figure B-1-9. Offline bioretention area where system fills to capacity and excess flow bypasses along curbline at inlet

Online

For online systems, all flow is routed through the bioretention area and excess runoff overflows an outlet structure. Outlet systems for online bioretention areas can be designed to provide some peak flow mitigation in addition to storing the design volume (see Designing for Peak Flow Mitigation). Appropriate energy dissipation should be incorporated in online systems such that media is not scoured during higher flow events. Two basic options can be used for outlets or overflow for online bioretention systems.

Appendix B.1 Bioretention Areas

Option 1: Vertical riser

1. An elevated outlet structure (typically an above-grade concrete drop inlet for larger bioretention areas or a PVC pipe for smaller bioretention areas) that is connected to the underdrain or directly to the drainage system.
2. The vertical riser should be sized to safely convey flow greater than the water quality volume. The vertical pipe will provide access for cleaning the underdrains.
3. The inlet to the riser should be set at the specified ponding depth and capped with an appropriate non-clogging grate. Figure B-1-10 shows an example of an online bioretention area with a vertical riser overflow design.

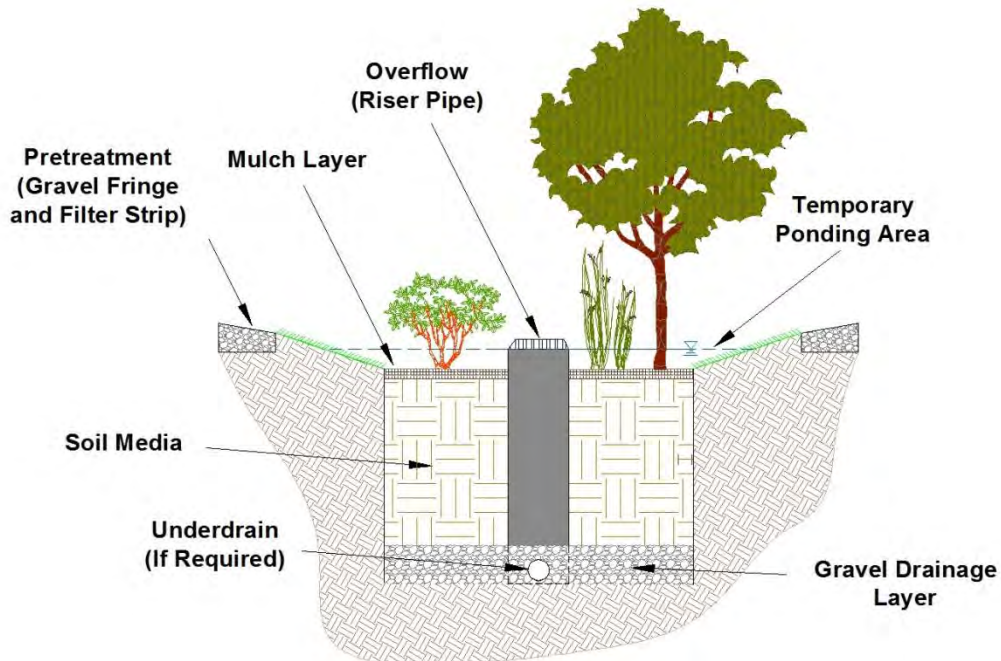


Figure B-1-10. Online bioretention area with a vertical rise overflow with a variable flow outlet structure

Option 2: Level spreader

1. A level spreader can be used to diffuse overflows from the bioretention area and should be installed along the exit edge or outflow section of the bioretention area. The level spreader should be concrete.
2. The top surface of the level spreader should be installed at a height equal to the ponding depth, or slightly greater if in conjunction with a vertical riser, to allow runoff exceeding the capacity of the bioretention area to safely pass.
3. The level spreader can be designed as a weir to allow for varied outlet flows providing some peak flow mitigation.
4. See [Common Design Elements](#) for details on level spreader design.

Typically, bioretention areas constructed in the right-of-way should be designed as offline stormwater treatment facilities. Once a bioretention area constructed in the right-of-way has reached capacity, stormwater flows should bypass the system and continue flow in the existing

stormwater drainage system or continue to the next BMP. If a bioretention area constructed in the right-of-way requires underdrains, a vertical riser overflow system can be incorporated as the primary overflow method in addition to the bypass.

Designing for Peak Flow Mitigation

Bioretention areas can be designed for peak flow mitigation (according to local regulations, as discussed in Chapter 2) by providing additional storage and, if necessary, modifying the outlet structure to discharge water at a controlled rate. Some additional water can be retained in the system above the water quality treatment volume for a short period without affecting the vegetation. If additional ponding depth is provided to store the flood control volume, maximum ponding depth must not exceed 18 inches. The riser should be designed to mitigate for the required peak flow without exceeding the maximum ponding time of 24 hours. This requirement can be achieved by incorporating an orifice or a weir with its invert at the elevation of the water quality treatment volume ponding depth (Figure B-1-11). Orifices that could be clogged by floating mulch or debris should be protected with a trash rack, a hood, or by installing a downturned pipe (for design of non-clogging orifices, see [Stormwater Wetlands](#)). The volume of water detained above the elevation of the drawdown orifice or weir cannot be credited toward the water quality treatment volume because this excess water will drain untreated to the storm sewer network without filtering through the soil media. Alternatively, underdrain outflow can be regulated using a restrictor plate, and all runoff can be routed through the soil media.



Figure B-1-11. Bioretention outlet structures designed for peak flow mitigation in Camp Pendleton, California (left) where a graduated riser pipe regulates drawdown of the detention volume; and Southwest Middle School, Gastonia, North Carolina (right) where orifices allow controlled dewatering of the detention volume and water quality treatment volume is retained below the orifice elevation. Source: Tetra Tech

Appendix B.1 Bioretention Areas

Discharge of the detention volume through orifices and weirs can be calculated using the following equations. For further guidance on hydraulic design, refer to USDA-SCS (1956) or Chow (1959).

$$\text{Orifice: } Q = C_d A \sqrt{2gH} \quad [\text{Equation B-1-4}]$$

$$\text{Weir: } Q = CLH^{3/2} \quad [\text{Equation B-1-5}]$$

where:

Q = discharge (cubic feet per second)

C_d = coefficient of discharge (0.6 for sharp openings, 0.8 for pipe openings)

A = cross sectional area of orifice (square feet)

g = acceleration due to gravity (32.2 ft/s²)

H = head of water acting on the structure (height of water over the centerline of the orifice or height of water over the crest of the weir; feet)

C = discharge coefficient (3.33 for broad-crested weir, 3.0 for sharp crested weir)

L = total length of weir (perpendicular to flow; feet)

Step 8. Select Mulch and Vegetation

Both mulch and vegetation are critical design components of bioretention areas from hydrologic, water quality, and aesthetic perspectives. Much of the biological activity in bioretention areas occurs in the mulch and root zone. The following subsections provide specifications for mulch and vegetation.

Mulch

Mulch is a critical component of the bioretention area because it provides a food source and habitat for many of the biological organisms critical to the function of the bioretention area. Much of the hydrocarbon, metals, and total suspended solids removal is believed to occur near the surface in the mulch layer (Hong et al. 2006; Hatt et al. 2008; Li and Davis 2008; Stander and Borst 2010). The bioretention area should be covered with mulch when constructed and annually replaced to maintain adequate mulch depth. Mulch is also important to sustain nutrient levels, suppress weeds, retain moisture for the vegetation, and maintain infiltrative capacity. Mulch should meet the following criteria:

- Dimensional chipped hardwood material is preferred for its permeability of both water and air. Well-aged, triple-shredded hardwood material can also be used if dimensional chipped hardwood material is unavailable (well-aged mulch is defined as mulch that has been stockpiled or stored for at least 12 months).
- Free of weed seeds, soil, roots, and other material that is not hardwood material.

- Mulch depth will be 2 to 4 inches thick, with 3 inches preferred (thicker applications can inhibit proper oxygen and carbon dioxide cycling between the soil and atmosphere).
- Grass clippings, pine nuggets, or pure bark should not be used as mulch.



Figure B-1-12. Triple-shredded hardwood mulch

Vegetation

One advantage of bioretention areas is that they can be used for the dual purpose of stormwater treatment and landscaping or be integrated into the existing landscape. Bioretention areas can be used toward meeting the 40 percent tree canopy cover goal of San Antonio's *SA2020 Plan*. For bioretention areas to function properly as stormwater treatment and blend into the landscape, vegetation selection is crucial. Appropriate vegetation will have the following characteristics:

1. Plant materials must be tolerant of summer drought and extreme heat, ponding fluctuations, and saturated soil conditions for 12 to 48 hours.
2. It is recommended that a minimum of three tree, three shrub, and three herbaceous groundcover species be incorporated to protect against facility failure from disease and insect infestations of a single species.
3. Vegetation with deep and extensive root systems are more tolerant of extreme hydroperiods and can effectively transpire large volumes of soil water. Planting deep-rooting vegetation directly above buried underdrains should be avoided (although interference of plant roots with underdrains is not a common maintenance issue).
4. Native plant species or noninvasive adapted cultivars that do not require chemical inputs are recommended to be used to the maximum extent practicable. Only native and noninvasive species will be selected in areas designated as natural open space.

Appendix B.1 Bioretention Areas

5. Shade trees should be free of branches for the bottom 1/3 of their total height and lines of sight must be maintained when planting along roadways.
6. Tree height and placement should consider overhead utilities.
7. If turfgrass is preferred, sod should be specified that was not grown in clay soils (or washed *bare root* sod should be specified).
8. An example list of native plants appropriate for bioretention areas in the San Antonio region is in Appendix E.

Many options exist for vegetation arrangement and will most likely depend on the landscaping of the area around the bioretention. Size-limited landscaping could be required for bioretention areas in the right-of-way to maintain the required sight distances. Consideration should be given to water depth, bioretention configuration, desired aesthetic appearance, and potential multi-use benefits. An example planting plan is shown in Figure B-1-13 and a plant list for the San Antonio region is provided in Appendix E.

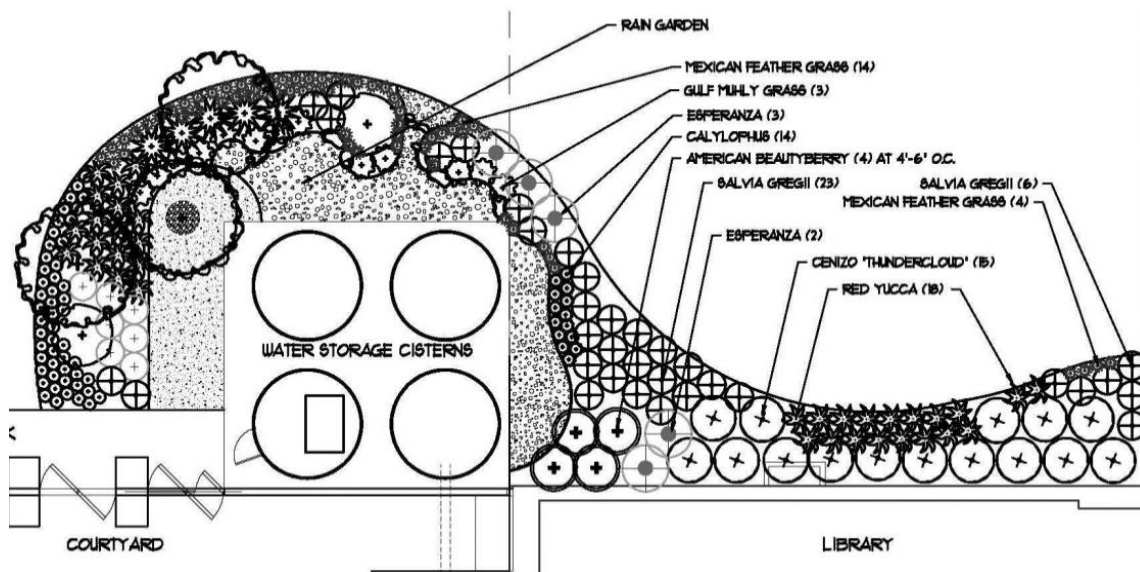


Figure B-1-13. Example bioretention planting plan

Encroachment of turf grasses present a long-term maintenance challenge. The vegetation plan should be designed in order to delay encroachment of problem grass species in the bioretention feature and facilitate maintenance activities to prevent or remove growth of unwanted grass within the bioretention. In order to keep grass out of planting areas use all of the following methods:

1. Isolate planting areas. Do not plant Bermuda in or near planting areas. Where applicable plant less aggressive grass species.
2. In areas already bordered by Bermuda grass:

- a. Install edging at least 8” below the surface.
- b. Install edging at least 2” above the surface.
- c. Install geotextile weed barrier at least 18” on planting side of edging.
- d. Cover geotextile with a minimum of 4” of inorganic mulch.

Peak flow rates for the design storm should also be calculated, using the methods outlined in Appendix A so that the inlet and pretreatment can be accordingly sized and flow attenuation can be considered

Step 9. Design for Multi-Use Benefits

Bioretention can provide excellent ecosystem services and aesthetic value to stakeholders. In addition to enhancing biodiversity and beautifying the urban environment with native vegetation, the following components can be incorporated into bioretention to promote multi-use benefits:

- Simple signage or information kiosks can educate the public on the benefits of watershed protection measures or provide a guide for native plant and wildlife identification (Figure B-1-14).
- Bird and butterfly feeders can be used to attract wildlife to the bioretention area.
- Sculptures and other art can be installed in the bioretention area, and outlet structures can be painted lively colors.
- Bioretention along the roadway (pop outs and curb extensions) can serve as a traffic calming features
- Ornamental plants can be cultivated along the perimeter and in the bed of bioretention areas (invasive plants should be avoided).
- Larger bioretention areas can be equipped with pedestrian cross-paths or benches for wildlife viewing (Figure B-1-15).
- Bioretention areas can function as irrigation beds for stormwater captured by other BMPs, such as rainwater harvesting or the reservoir layer of permeable pavement (Figure B-1-16).
- Vegetation with canopy cover can provide shade, localized cooling, and noise dissipation.
- Volunteer groups can be organized to perform basic maintenance as an opportunity to raise public awareness.



Figure B-1-14. Signage posted in front of ultra-urban bioretention area raises public awareness



Figure B-1-15. Cobbled bioretention area that invites pedestrian interaction at the offices of Bender Wells Clark Design. Source: Bender Wells Clark Design



Figure B-1-16. Overflow from a rainwater cistern is discharged to a cobbled bioretention area at Mission Library, San Antonio, Texas. Source: Bender Wells Clark Design

B.1.2 Critical Construction Considerations

Construction technique and sequencing are critical to bioretention cell performance. Failure of improperly constructed systems can be easily avoided by effective communication with the contractor and by inspection during key steps. In addition to the general construction considerations provided in Chapter 4, emphasizing the following points will help ensure successful installation of bioretention cells.

B.1.2.1 Minimize and Mitigate Compaction by Scarifying Subsoil Surface

Compaction of underlying soils (an inherent consequence of construction) can decrease infiltration rates and result in poor drainage, extended periods of standing water, plant die-off, and, in some cases, leaching of previously captured pollutants. Construction effects on underlying soils can be mitigated by excavating the last 12 inches of cut with a toothed excavator bucket. This method breaks up compacted layers and prevents *smearing*, which can seal the subsoil surface (Brown and Hunt 2010). Infiltration can also be significantly enhanced by ripping or trenching the subsoils to a depth of 9–12 inches (Tyner et al. 2009). Ripped furrows (on 3-foot centers) should be filled with a clean sand to maintain free-flowing conditions. Trenches are typically constructed 12 inches wide on 6-foot centers and are filled with pea gravel.

B.1.2.2 Inspect Soil Media Before Placement

It is important to ensure that the soil media is consistent with specifications before installation—media that is too sandy will not provide adequate treatment, whereas media that is too fine might not drain in adequate time (Carpenter and Hallam 2010). To field-verify the texture of soil media, moisten the soil and form into a 1-inch ball. Drop the ball from 1 foot onto the open palm of the hand. The ball should break apart on impact, indicating that it is a sandy soil. When rubbed between the fingers, the moist soil should also leave a thin layer of mud residue on the skin, indicating that fines are present in the mix. Soil media should also contain a small amount of plant-based organic matter evenly distributed throughout the mix—the organic matter should not smell like manure. Note: These inspection techniques are intended for field verification and do *not* substitute for laboratory soil test results.

B.1.2.3 Verify that Average Ponding Depth is Provided

It is important to verify that the intended design volume of runoff can be captured by the bioretention cell. Contractors who are unfamiliar with construction of bioretention may try to minimize surface ponding by installing the outlet elevation too low. Cells that do not provide their intended capacity of surface storage will overflow more often than intended and discharge untreated runoff to waterways (Brown and Hunt 2011b; Luell et al. 2011). Therefore, it is critical to check that the average surface ponding depth has been provided and that the bed of the cell has been uniformly graded—this can be performed by simply verifying the overflow/bypass elevation of the system relative to the average elevation of the mulch bed surface. An average depth must be measured because the height of the outlet structure relative to adjacent ground surface is not a reliable indicator of average ponding depth (Wardynski and Hunt 2012). Excessive mulch (deeper than 4 inches) can also displace surface storage volume and should be avoided.

B.1.3 Operation and Maintenance

Bioretention areas require regular plant, soil, and mulch layer maintenance to ensure optimum infiltration, storage, and pollutant-removal capabilities. Table B-1-5 provides a detailed list of maintenance activities and general maintenance considerations are provided in Section 4.3. In general, bioretention maintenance requirements are typical landscape care procedures and consist of the following:

1. Erosion control: Inspect flow entrances, ponding area, and surface overflow areas periodically during the rainy season, and replace soil, plant material, or mulch layer in areas if erosion has occurred (for a bioretention inspection and maintenance checklist, see Appendix F). Properly designed facilities with appropriate flow velocities should not have erosion problems except perhaps in extreme events. If erosion problems occur, the following must be reassessed: (1) flow velocities and gradients within the cell, and (2) flow dissipation and erosion protection strategies in the pretreatment area and flow entrance. If sediment is deposited in the bioretention area, immediately determine the source within the contributing area, stabilize, and remove excess surface deposits. Any exposed soil in the catchment should be permanently stabilized with grass, rock, or other erosion-resistant materials (per TxDOT 2011).
2. Inlet: The inlet of the bioretention area should be inspected after the first storm of the season, then monthly during the rainy season to check for sediment accumulation and erosion. Sediment can accumulate especially at inlets where curb cuts or bypass structures are used and should be inspected regularly. Any accumulated sediment that impedes flow into the bioretention area should be removed and properly disposed of.
3. Overflow and underdrains: Sediment accumulation in the overflow device or underdrain system can cause prolonged ponding and potential flooding. Excess ponding can have adverse effects on vegetation and vector control. Overflow and underdrain systems should be inspected after the first storm of the season, then monthly during the rainy season to remove sediment and prevent mulch accumulation around the overflow. The underdrain system should be designed so that it can be flushed and cleaned as needed. If water is ponded in the bioretention area for more than 72 hours, the underdrain system should be flushed with clean water until proper infiltration is restored.
4. Plant material: Depending on aesthetic requirements, occasional pruning and removing dead plant material might be necessary. Replace all dead plants, and if specific plants have a high mortality rate, assess the cause and, if necessary, replace with more appropriate species. Periodic weeding is necessary until plants are established. The weeding schedule can become less frequent if the appropriate plant species and planting density have been used and, as a result, undesirable plants are excluded.
5. Nutrient and pesticides: The soil mix and plants are selected for optimum fertility, plant establishment, and growth. Nutrient and pesticide inputs should not be required and can degrade the pollutant processing capability of the bioretention area and contribute pollutant loads to receiving waters. By design, bioretention areas are located in areas where phosphorous and nitrogen levels are often elevated, and they should not be limiting nutrients. If in question, have the soil analyzed for fertility.
6. Mulch: Replace mulch annually in bioretention areas where heavy metal deposition is likely (e.g., contributing areas that include industrial and auto dealer/repair parking lots and roads). In areas where metal deposition is not a concern, add mulch as needed to maintain a 2- to 3-inch depth. Mulch should be replaced every 2 to 5 years.
7. Soil: Soil mixes for bioretention areas are designed to maintain long-term fertility and pollutant processing capability. Estimates from metal attenuation research suggest that

Appendix B.1 Bioretention Areas

metal accumulation should not present an environmental concern for at least 20 years in bioretention systems. Replacing mulch in bioretention areas where heavy metal deposition is likely provides an additional level of protection for prolonged performance. If in question, have the soil analyzed for fertility and pollutant levels and consult local regulations for disposal protocol.

8. Watering: Plants must be selected to be drought tolerant and not require watering after establishment (2 to 3 years). Watering could be required during prolonged dry periods after plants are established.

Table B-1-5. Inspection and maintenance tasks

Task	Frequency	Indicator maintenance is needed	Maintenance notes
Catchment inspection	Weekly or biweekly with routine property maintenance	Excessive sediment, trash, or debris accumulation on the surface of bioretention.	Permanently stabilize any exposed soil and remove any accumulated sediment. Adjacent pervious areas might need to be re-graded.
Inlet inspection	Weekly or biweekly with routine property maintenance	Internal erosion or excessive sediment, trash, and/or debris accumulation	Check for sediment accumulation to ensure that flow into the bioretention is as designed. Remove any accumulated sediment.
Litter and leaf litter removal	Weekly or biweekly with routine property maintenance	Accumulation of litter and leafy debris within bioretention area	Litter and leaves should be removed to reduce the risk of outlet clogging, reduce nutrient inputs to the bioretention area, and to improve facility aesthetics.
Pruning	1–2 times/year	Overgrown vegetation that interferes with access, lines of sight, or safety	Nutrients in runoff often cause bioretention vegetation to flourish.
Mowing	2–12 times/year	Overgrown vegetation that interferes with access, lines of sight, or safety	Frequency depends on location and desired aesthetic appeal.
Mulch removal and replacement	1 time/2–3 years	Less than 3 inches of mulch remains on surface	Mulch accumulation reduces available surface water storage volume. Removal of decomposed mulch also increases surface infiltration rate of fill soil. Remove decomposed fraction and top off with fresh mulch to a total depth of 3 inches
Temporary Watering	1 time/2–3 days for first 1–2 months, sporadically after established	Until established and during severe droughts	Watering after the initial year might be required.
Fertilization	1 time initially	Upon planting	One-time spot fertilization for first year vegetation if needed.
Remove and replace dead plants	1 time/year	Dead plants	Plant die-off tends to be highest during the first year (commonly 10% or greater). Survival rates increase with time.
Outlet inspection	Once after first rain of the season, then monthly during the rainy season	Erosion at outlet	Remove any accumulated mulch or sediment.
Miscellaneous upkeep	12 times/year	Tasks include trash collection, plant health, spot weeding, removing invasive species, and removing mulch from the overflow device.	

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B.2 Bioswales



Bioswale at City of San Antonio Development Services Department parking lot, San Antonio, Texas.

B.2.1 Design

The design of a bioswale is very similar to a bioretention area and can similarly be broken down to a nine-step process, as outlined in Table B-2-1. Unlike [vegetated swales](#) that provide limited horizontal filtration and sedimentation, bioswales are intended to filter runoff vertically through soil media; conveyance should be considered a secondary design element.

Table B-2-1. Iterative design step process

Design step		Design component/ consideration	General specification
1	Determine BMP Size (B-37)	Use Appendix A	
2	BMP Siting (B-37)	Based on available space and maintenance access, incorporate into parking lot islands, medians, and perimeter; install along the roadway right-of-way; incorporate as landscaped areas throughout the property.	
3	Determine BMP Function and Configuration (B-38)	Impermeable liner	If non-infiltrating (per geotechnical investigation), use impermeable clay liner, geomembrane, or concrete (as described in Common Design Elements).
		Lateral hydraulic restriction barriers	Use concrete or geomembrane to restrict lateral seepage to adjacent subgrades, foundations, or utilities.
		Underdrain (required if subsoil infiltration rate is less than 0.5 in/hr)	Schedule 40 PVC pipe with perforations (slots or holes) every 6 inches. 4-inch diameter lateral pipes should join a 6-inch collector pipe, which conveys drainage to the downstream storm network. Provide cleanout ports/observation wells for each underdrain pipe at spacing consistent with local regulations. See Common Design Elements
		Internal water storage (IWS)	If using underdrain and infiltration, elevate the outlet to create a sump for additional moisture retention to promote plant survival and treatment. Top of IWS should be greater than 18 inches below surface.
		No underdrain	If design is fully infiltrating, ensure that subgrade compaction is minimized.
4	Size the System (B-40)	Temporary ponding depth	Use check dams to provide 6-18 inches surface ponding (6-12 inches near schools or in residential areas); average ponding depth of 9 inches is recommended
		Soil media depth	2-4 feet (deeper for better pollutant removal, hydrologic benefits, and deeper rooting depths)
		Slope and grade control	If necessary, use check dams to maintain maximum 2% bed slope. Install a 4-inch deep layer of ASTM No. 57 stone (underlain by filter fabric) extending 2 feet downslope from check dam to prevent erosion.
		Surface area	Accounting for slope, find surface area required to store treatment volume within temporary ponding depth, soil media depth, and gravel drainage layer depth (media porosity \approx 0.35 and gravel porosity \approx 0.4)
5	Specify Soil Media (B-42)	Media composition and texture	85-88% sand, 8-12% fines, 2-5% plant-derived organic matter (animal wastes or by-products should not be applied)
		Media permeability	1-6 in/hr infiltration rate (1-2 in/hr recommended)
		Chemical analysis	Total phosphorus < 15 ppm, pH 6-8, CEC > 5 meq/100 g soil

Design step		Design component/ consideration	General specification
		Drainage layer	Separate soil media from underdrain with 2–4 inches of washed concrete sand (ASTM C33), followed by 2 inches of choking stone (ASTM No. 8) over a 1.5 ft envelope of ASTM No. 57 stone.
6	Design Inlet and Pretreatment (B-42)	Inlet	Provide stabilized inlets (see Common Design Elements)
		Pretreatment	Install rock armored forebay (concentrated flow), gravel fringe and vegetated filter strip (sheet flow), or vegetated swale
7	Select and Design Overflow/Bypass Method (B-42)	Outlet configuration	Online: All runoff is routed through system—install an elevated overflow structure or weir at the elevation of maximum ponding Offline: Only treated volume is diverted to system—install a diversion structure or allow bypass of high flows
		Peak flow mitigation	Provide additional detention storage and size an appropriate non-clogging orifice or weir to dewater detention volume
8	Select Mulch and Vegetation (B-43)	Mulch	Dimensional chipped hardwood or triple shredded, well-aged hardwood mulch 3 inches deep.
		Vegetation	See Plant List (Appendix E)
9	Design for Multi-Use Benefits (B-44)	Include features to enhance habitat, aesthetics, public education, and shade.	

Step 1. Determine BMP Size

The bioswale must be sized to fully capture the desired or required design storm volume and filter it through the soil media. Relevant regulatory requirements are presented in detail in Chapter 2. Surface storage (in the ponding area) and soil pore space (in the plant rooting zone and the underlying media and gravel drainage layers) provide capacity for the design storm volume retention. Appendix A outlines methods for determining design runoff depths associated with a range of annual treatment efficiencies. Once the design runoff depth is determined (on the basis of the desired level of treatment), a runoff volume can be determined for the contributing watershed using this depth and the methods outlined in Appendix A, *San Antonio Unified Development Code*, or *San Antonio River Basin Regional Modeling Standards for Hydrology and Hydraulic Modeling*.

Peak flow rates for the design storm should also be calculated, using the methods outlined in Appendix A so that the inlet and pretreatment can be accordingly sized and flow attenuation can be considered.

Step 2. BMP Siting

Bioswales are intended to provide the same function as a bioretention area with the same pollutant-removal capacity with a narrow width to be more easily configured into the site plan for parking lot edges and narrow rights-of-way. Bioswales are a versatile stormwater BMP because they can effectively reduce pollutants and can be integrated into the site plan with various configurations and components. Stormwater treatment should be considered as an integral component and incorporated in the site design and layout from conception. Many times, determining how the bioswale will be included in the site design is a critical and required first step. How the water is routed to the bioswale and the available space will be key components in determining how the bioswale will be configured. Access for maintenance activities must also be provided. Site

Appendix B.2 Bioswales

assessment, planning, and site design are discussed in detail in Section 1.6. The following is a list of settings where bioswales can be incorporated to meet more than one project-level or watershed-scale objective:

- Along the edge and between parking stalls in parking lots
- Within rights-of-way along roads

How the bioswale is configured determines the required components. Pretreatment at some level is always recommended to remove gross solids where possible and reduce flows to a non-erosive rate. Curb cuts can be required to allow stormwater to enter the bioswale, while providing some delineation in high-traffic areas. Bioswales can serve the dual purpose of stormwater management and landscape design and can significantly enhance the aesthetics of a site. Figure B-2-1 shows an example of the components of a typical bioswale. Bioswales typically have multiple components including the following:

- Filter strip or grass buffer for pretreatment
- Media layer for filtration
- Ponding area for storage
- Plants for pollutant uptake and landscaping

In addition, bioswales can be combined with other BMPs to form a treatment train that can provide enhanced water quality treatment and reductions in runoff volume and rate. For example, runoff can be collected from a roadway or a parking lot in a bioswale that then overflows to a bioretention area. Both facilities can be reduced in size on the basis of demonstrated performance for meeting the stormwater runoff requirements as outlined in Chapter 2 and addressing targeted pollutants of concern.

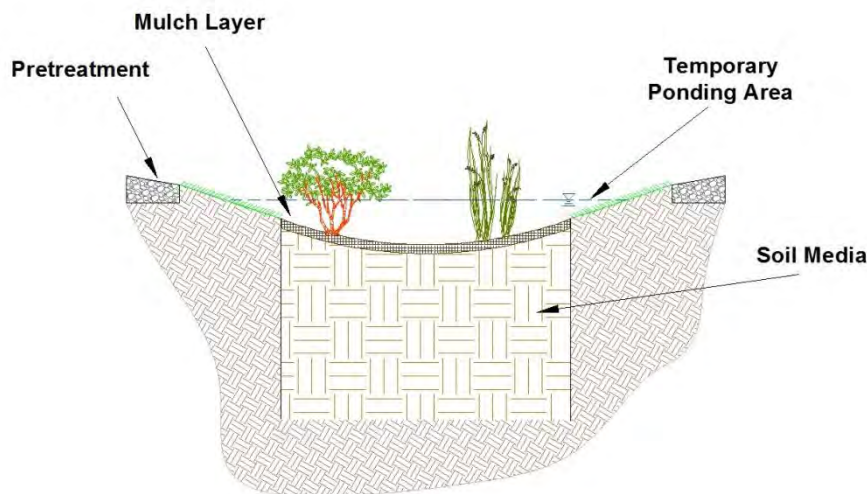


Figure B-2-1. Bioswale components

Step 3. Determine BMP Function and Configuration

Bioswales can be designed as infiltrating or filtering BMPs, similar to [bioretention](#). Because of the narrow configuration of a bioswale and its intended use along the edges of parking lots and roads,

infiltration pathways will most likely need to be restricted to prevent unintended effects on roads, foundations, other infrastructure, or hotspot locations. In some conditions, lateral seepage can cause damage to surrounding structures depending on the type of soils in the area (Figure B-2-2). Areas that have a potential for settling under saturated conditions, as determined in the geotechnical investigation, should be protected from lateral flows. Types of clay that have a high potential for expansion when saturated should be protected from moisture in load-bearing conditions. For details on hydraulic restriction barriers, see [Common Design Elements](#).

Where infiltration is allowed, IWS can be used to enhance exfiltration, pollutant removal, and soil moisture for plant health (Li et al. 2010; Brown and Hunt 2011; Barrett et al. 2012; Houdeshel et al. 2012). As with [bioretention](#), the IWS zone should be at least 18 inches below the surface throughout the length of the bioswale. Excavating the subgrade in tiers and creating partitions between cells of the bioswale will further improve performance by providing more uniform exfiltration across the subgrade (as illustrated in Figure B-2-3).

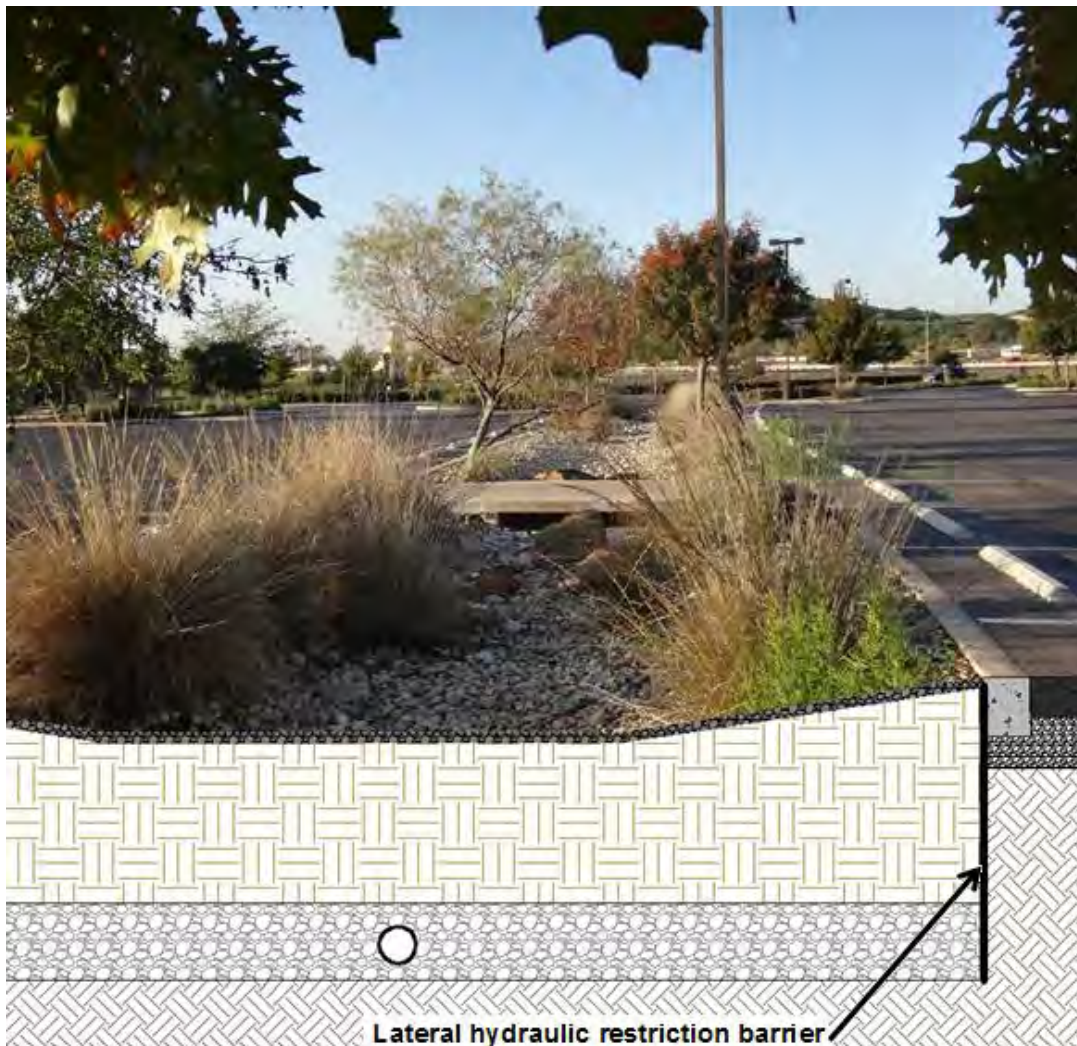


Figure B-2-2. Bioswale at Rim Retail Center, San Antonio, Texas showing example cross section with hydraulic restriction barrier to prevent lateral seepage to adjacent pavement subgrade.

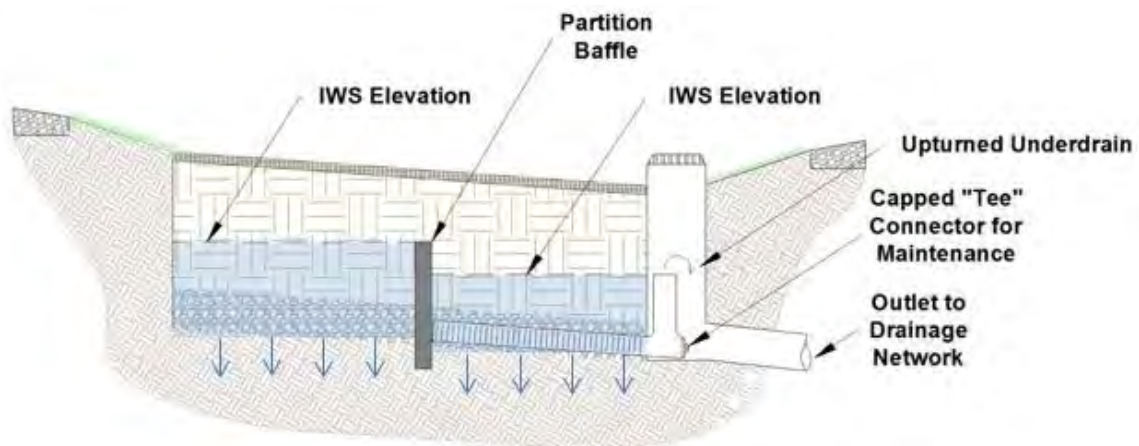


Figure B-2-3. Bioswale incorporating a partition baffle to enhance exfiltration

Step 4. Size the System

The bioswale water quality treatment volume can be determined by using Appendix A. The following subsections discuss sizing bioswales for water quality and conveyance.

Geometry, Temporary Ponding Depth, and Soil Media Depth

Bioswale dimensions have similar standards to bioretention areas except that they are typically long and narrow with widths between 2 and 8 feet. Bioswales have a maximum ponding depth of 18 inches, with an average depth of 9 inches. Soil media depth should be specified according to the pollutant of concern, hydrologic goals, and drainage configuration, as outlined in the [bioretention](#) section.

Slope and Grade Control

Bioswales are to be sized to capture and treat the volume produced by the design storm and, where site conditions allow, should also be sized to infiltrate the volume-reduction requirement. For the stormwater runoff requirements and calculations, see Appendix A. If the bioswale will have longitudinal slope (parallel to flow), flow velocity should generally not exceed 1 ft/sec in mulched swales and 3 ft/sec in grassed swales and the shear stress should not exceed the permissible shear stress of the bed materials, as suggested in TxDOT (2011). Guidance for calculating flow velocity is provided in the [vegetated swales](#) section. Check dams might be required to ensure retention and infiltration of the design storm volume into the soil media. The maximum bed slope of the bioswale may not exceed 2 percent to prevent erosion, but bioswales with check dams may contain average slopes (from upslope to downslope end) of up to 5 percent (the bed slope of each section between check dams must be 2 percent or less). Check dams should be adequately embedded in the side slopes and can be constructed of concrete, metal sheet pile, or wood (Figure B-2-4). Earthen and stone check dams should not be used because of risk of erosion. The area downslope of check dams should be armored with at least a 4-inch-deep gravel or cobble layer extending 2 feet from the base of the check dam (as shown in Figure B-2-5). Gravel should consist of No. 57 stone and should be underlain by geotextile to prevent scour and erosion of underlying soil. Cobble can be mortared to prevent removal.



Figure B-2-4. Bioswale with a check dam, Los Angeles, California. Source: Tetra Tech

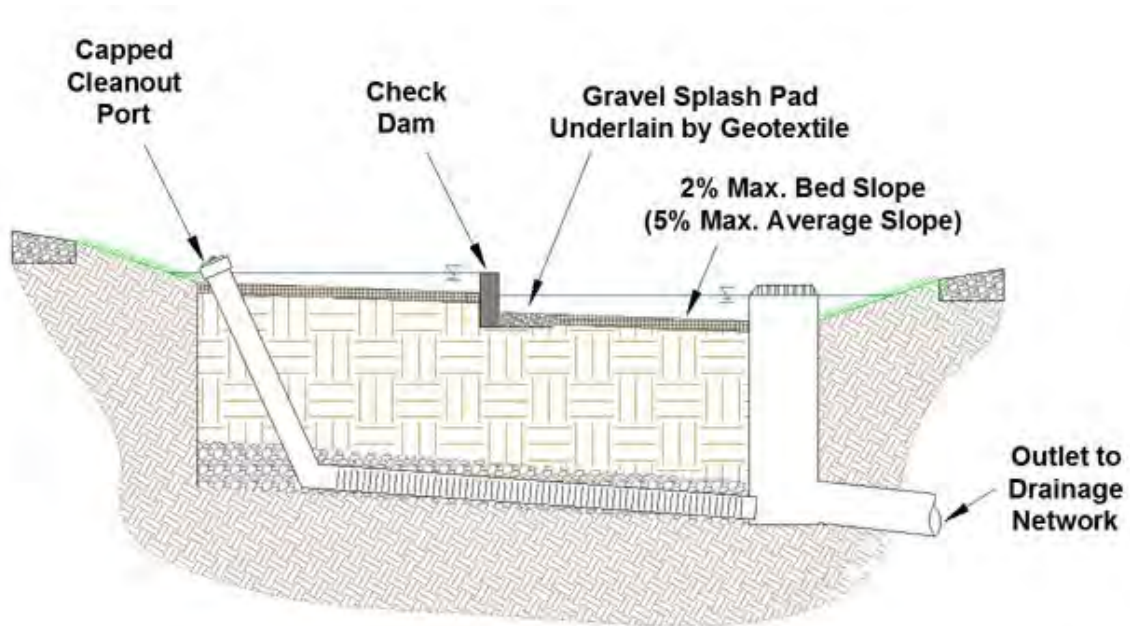


Figure B-2-5. Example profile of a bioswale with a check dam to retain the design storm volume

Appendix B.2 Bioswales

Size surface area

The footprint of the bioswale should be calculated following the methods provided in the [bioretention](#) section, but slope must be taken into account when specifying an average ponding depth. The required surface area can be calculated using the equations in the [bioretention](#) section assuming a nine-inch ponding depth. The swale configuration should be adjusted to attain the desired surface area. If the bed of the bioswale is sloped, the required number of check dams to create the desired ponding depth can be estimated using the following equations:

$$N = \frac{L_{swale} \times S}{h_{dam}} \quad \text{[Equation B-2-1]}$$

$$L_{dam} = \frac{L_{swale}}{N} \quad \text{[Equation B-2-2]}$$

where:

N = number of check dams required

L_{swale} = total length of bioswale (ft)

S = longitudinal slope of bioswale (ft/ft)

$h_{dam} = (2 \times D_{surface})$ = height of check dams (ft; use a maximum height of 1.5)

L_{dam} = distance between check dams (ft)

The above equation is simplified and should be adjusted on the basis of specific site conditions and bioswale configuration. The slope of a site can vary, the number of check dams required should be calculated separately for each significant change in slope.

Step 5. Specify Soil Media

The soil media in the bioswale should meet the requirements specified in the [bioretention](#) section.

Step 6. Design Inlet and Pretreatment

Inlets must be designed to convey the design storm volume into the bioswale while limiting ponding or flooding at the entrance and protecting the interior from damage. Several options are available depending on the configuration of the bioswale. Ideally, runoff will pass over a filter strip where flow can be dispersed and gross solids removed before it enters the bioswale. That is not always possible, especially in retrofit situations where space might not be available. Methods used for designing [bioretention inlets and pretreatment](#) are applicable to bioswales. Typical inlet configurations are also described in [Common Design Elements](#).

Step 7. Select and Design Overflow/Bypass Method

Bioswales, like bioretention, can be designed as either offline or online systems (for design guidance, see [bioretention](#)). Examples of offline and online bioswales are shown in Figure B-2-6. When flows through a bioswale could exceed the recommended maximum flow rates, regardless of whether a system is designed to be online or offline, a bypass structure is recommended to prevent erosion in the bioswale. The flow velocity in a mulched system should not exceed 1 ft/sec, and flow in a grassed system should not exceed 3 ft/sec. Flows can be greater (up to 14 ft/sec) with

the use of reinforced turf matting and will depend on the matting selected. Flow rate can be calculated using methods in TxDOT (2011).



Figure B-2-6. An offline bioswale (left) along the road right of way with excess flow bypass along the gutter line at the Doseum, San Antonio Texas; and an online bioswale (right) with an overflow outlet structure along a roadway and parking lot that is part of a treatment train with an adjacent detention basin, San Antonio, Texas.

Step 8. Select Mulch and Vegetation

Both mulch and vegetation are critical design components of bioswales from hydrologic, water quality, and aesthetic perspectives. The following subsections provide specifications for mulch and vegetation.

Mulch

Bioswales intended to be mulched must be covered with mulch when constructed and annually replaced to maintain adequate mulch depth. Mulch can help sustain nutrient levels, suppress weeds, and maintain infiltrative capacity. Mulch should meet the specifications provided in the [bioretention](#) section.

Vegetation

One advantage of a bioswale, similar to bioretention areas, is that they can be used for the dual purpose of stormwater treatment and landscaping or be integrated into the existing landscape. For

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bioswales to function properly as stormwater treatment and blend into the landscaping, vegetation selection is crucial. Appropriate vegetation will have the following characteristics:

1. Plant materials must be tolerant of summer drought, ponding fluctuations, and saturated soil conditions for 10 to 48 hours.
2. It is recommended that a minimum of three tree, three shrub, and three herbaceous groundcover species be incorporated to protect against facility failure from disease and insect infestations of a single species. Plant rooting depths must not damage the underdrain, if present. Slotted or perforated underdrain pipe must be more than 5 feet from tree locations (if space allows).
3. Native plant species or adapted noninvasive cultivars that do not require chemical inputs are recommended to be used to the maximum extent practicable.
4. Shade trees should be free of branches for the bottom 1/3 of their total height and lines of sight must be maintained when planting along roadways.
5. A list of native plants appropriate for San Antonio is in Appendix E.

Endless options for vegetation arrangement are available, and the one chosen will most likely depend on the landscaping of the area around the bioswale.

Encroachment of turf grasses present a long-term maintenance challenge. The vegetation plan should be designed in order to delay encroachment of problem grass species in the bioswale feature and facilitate maintenance activities to prevent or remove growth of unwanted grass within the bioswale. In order to keep grass out of planting areas use all of the following methods:

1. Isolate planting areas. Do not plant Bermuda in or near planting areas. Where applicable plant less aggressive grass species.
2. In areas already bordered by Bermuda grass:
 - a. Install edging at least 8" below the surface.
 - b. Install edging at least 2" above the surface.
 - c. Install geotextile weed barrier at least 18" on planting side of edging.
 - d. Cover geotextile with a minimum of 4" or inorganic mulch

Step 9. Design for Multi-Use Benefits

Because of their adaptability to many different settings, bioswales can be designed to provide all of the beneficial uses specified in the [bioretention](#) section.

B.2.2 Critical Construction Considerations

Construction technique and sequencing are critical to bioretention cell performance. For construction and implementation notes, see [bioretention](#) and Chapter 4.

B.2.3 Operation and Maintenance

Bioswales, similar to bioretention areas, require regular plant, soil, and mulch layer maintenance to ensure optimum infiltration, storage, and pollutant-removal capabilities. Table B-2-2 lists

maintenance tasks for bioswales. In general, bioswale maintenance requirements are typical landscape care procedures and consist of the following:

1. **Erosion control:** Inspect flow entrances, ponding area, and surface overflow areas periodically during the rainy season, and replace soil, plant material, or mulch layer in areas if erosion has occurred (for a bioswale inspection and maintenance checklist, see Appendix F). Properly designed facilities with appropriate flow velocities will not have erosion problems except perhaps in extreme events. If erosion problems occur, the following must be reassessed: (1) flow velocities and gradients within the cell, and (2) flow dissipation and erosion protection strategies in the pretreatment area and flow entrance. If sediment is deposited in the bioswale, immediately determine the source in the contributing area, stabilize, and remove excess surface deposits. Any exposed soil in the catchment should be permanently stabilized with grass, rock, or other erosion-resistant materials per TxDOT (2011).
2. **Inlet:** The inlet area should be inspected after the first storm of the season, then monthly during the rainy season to check for sediment accumulation and erosion. Sediment can accumulate especially at inlets where curb cuts or bypass structures are used and should be inspected regularly. Any accumulated sediment that impedes flow into the bioswale should be removed and properly disposed of.
3. **Overflow and underdrains:** Sediment accumulation in the overflow device or underdrain system can cause prolonged ponding and potential flooding. Excess ponding can have adverse effects on vegetation and vector control. Overflow and underdrain systems should be inspected after the first storm of the season, then monthly during the rainy season to remove sediment and prevent mulch accumulation around the overflow. The underdrain systems should be designed so that it can be flushed and cleaned as needed. If water is ponded in the bioswale for more than 72 hours, the underdrain system should be flushed with clean water until proper infiltration is restored.
4. **Plant material:** Depending on aesthetic requirements, occasional pruning and removing of dead plant material might be necessary. Replace all dead plants, and if specific plants have a high mortality rate, assess the cause and, if necessary, replace with more appropriate species. Periodic weeding is necessary until plants are established. The weeding schedule could become less frequent if the appropriate plant species and planting density have been used and, as a result, undesirable plants are excluded.
5. **Nutrient and pesticides:** The soil mix and plants are selected for optimum fertility, plant establishment, and growth. Nutrient and pesticide inputs should not be required and can degrade the pollutant processing capability of the bioswale, and contribute pollutant loads to receiving waters. By design, bioswales are located in areas where phosphorous and nitrogen levels are often elevated, and those should not be limiting nutrients. If in question, have the soil analyzed for fertility.
6. **Mulch:** Replace mulch annually where heavy metal deposition is likely (e.g., contributing areas that include industrial and auto dealer/repair parking lots and roads). In areas where metal deposition is not a concern, add mulch as needed to maintain a 2- to 3-inch depth. Mulch should be replaced every 2 to 5 years.
7. **Soil:** Soil mixes are designed to maintain long-term fertility and pollutant processing capability. Estimates from metal attenuation research suggest that metal accumulation should not present an environmental concern for at least 20 years. Replacing mulch where heavy metal deposition is likely provides an additional level of protection for prolonged performance. If in question, have soil analyzed for fertility and pollutant levels and check local regulations for disposal protocol.

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8. Watering: Drought-tolerant plants should be selected to reduce watering after establishment (2 to 3 years). Watering might be required during prolonged dry periods after plants are established.

Table B-2-2. Inspection and maintenance tasks

Task	Frequency	Indicator maintenance is needed	Maintenance notes
Catchment inspection	Weekly or biweekly with routine property maintenance	Excessive sediment, trash, or debris accumulation on the surface of bioswale.	Permanently stabilize any exposed soil and remove any accumulated sediment. Adjacent pervious areas might need to be re-graded.
Inlet inspection	Weekly or biweekly with routine property maintenance	Internal erosion or excessive sediment, trash, or debris accumulation	Check for sediment accumulation to ensure that flow into the bioretention is as designed. Remove any accumulated sediment.
Litter and leaf litter removal	Weekly or biweekly with routine property maintenance	Accumulation of litter and leafy debris in the bioswale area	Litter and leaves should be removed to reduce the risk of outlet clogging, reduce nutrient inputs to the bioretention area and to improve facility aesthetics.
Pruning	1–2 times/year	Overgrown vegetation that interferes with access, lines of sight, or safety	Nutrients in runoff often cause bioretention vegetation to flourish.
Mowing	2–12 times/year	Overgrown vegetation that interferes with access, lines of sight, or safety	Frequency depends on location and desired aesthetic appeal.
Mulch removal and replacement	1 time/2–3 years	Less than 3 inches of mulch remains on the surface	Mulch accumulation reduces available surface water storage volume. Removing decomposed mulch also increases surface infiltration rate of fill soil. Remove decomposed fraction and top off with fresh mulch to a total depth of 3 inches
Temporary Watering	1 time/2–3 days for first 1–2 months, sporadically after established	Until established and during severe droughts	Watering after the initial year might be required.
Fertilization	1 time initially	Upon planting	One-time spot fertilization for first year vegetation if needed.
Remove and replace dead plants	1 time/year	Dead plants	Plant die-off tends to be highest during the first year (commonly 10% or greater). Survival rates increase with time.
Outlet inspection	Once after first rain of the season, then monthly during the rainy season	Erosion at outlet	Remove any accumulated mulch or sediment.
Miscellaneous upkeep	12 times/year	Tasks include trash collection, plant health, spot weeding, removing invasive species, and removing mulch from the overflow device.	

B.2.4 References

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B.3 Permeable Pavement



**Permeable pavement parking stalls at the Oaks at University Business Park, San Antonio, Texas.
Source: Bender Wells Clark Design**

B.3.1 Design

The design of a permeable pavement system follows a nine-step process, as described in Table B-3-1.

Table B-3-1. Iterative design step process

Design step	Design component/ consideration	General specification
1 Determine BMP Size (B-50)	Use Appendix A	
2 BMP Siting (B-50)	Based on available space, incorporate into parking lots (solely parking stalls or parking stalls and driving lanes), parking lanes along roadways, pedestrian sidewalks and plazas, and fire access roads. If outside the Edwards Aquifer Contributing Zone or if the system will be lined with an impermeable liner, runoff from adjacent impervious surfaces less than or equal to the permeable pavement area is allowed.	
3 Select Permeable Pavement Surface Course (B-52)	Surface course type	Pervious concrete, porous asphalt, and permeable interlocking concrete pavers (PICP) are the preferred types of permeable pavement because detailed industry standards and certified installers are available. Concrete grid pavers and plastic grid systems also have useful applications.
4 Determine BMP Function and Configuration (B-61)	Impermeable liner	If non-infiltrating (per geotechnical investigation), use impermeable clay liner, geomembrane, or concrete (as described in Common Design Elements)
	Lateral hydraulic restriction layers	Use concrete or geomembrane to restrict lateral flows to adjacent subgrades, foundations, or utilities.
	Underdrain (required if subsoil infiltration rate < 0.5 in/hr)	Schedule 40 PVC pipe with perforations (slots or holes) every 6 inches. 4-inch diameter lateral pipes should join a 6-inch collector pipe, which conveys drainage to the downstream storm network. Provide orifice at underdrain outlet sized to release water quality volume over 2-5 days. See Common Design Elements
	Internal water storage (IWS)	If using underdrain and infiltration is feasible, elevate the outlet to create a sump to enhance infiltration and treatment.
	No underdrain	If design is fully infiltrating, ensure that subgrade compaction is minimized.
	Observation wells	Provided capped observation wells to monitor drawdown.
5 Design the Profile (B-64)	Temporary surface ponding depth (Edwards Aquifer Zones)	Surface ponding should be provided (by curb and gutter) to capture the design storm in the event that the permeable pavement surface clogs
	Specify sand/soil filter layer	<ul style="list-style-type: none"> • With underdrains: min. 3-inch layer of ASTM C-33 washed sand above gravel of underdrain drainage layer. A 2-inch layer of choking stone between sand and gravel might be needed. • No underdrains: min. 12-inch subsoil (see Common Design Elements)

Appendix B.3 Permeable Pavement

Design step	Design component/ consideration	General specification
	Calculate surface area and reservoir depth	Water quality volume should be fully stored within the aggregate base layers below the surface course. Base layer should be washed ASTM No. 57 stone (washed ASTM No. 2 may be used as a subbase layer for additional storage).
	Structural design	A pavement structural analysis should be completed by a qualified and licensed professional
6	Design for Safe Bypass/Conveyance of Larger Storms (B-65)	<ul style="list-style-type: none"> • Poured in place systems (pervious concrete or porous asphalt): system can overflow internally or on the surface • Modular/Paver-type systems (PICP): internal overflow is required to prevent upflow and transport of bedding course
7	Design Edge Restraints and Transitions (B-66)	Provide a concrete transition strip between any permeable and impermeable surfaces and around the perimeter of PICP installations
8	Design Signage (B-67)	Signage should prohibit activities that cause premature clogging and indicate to pedestrians and maintenance staff that the surface is intended to be permeable
9	Design for Multi-Use Benefits (B-67)	Provide educational signage, enhanced pavement colors, or stormwater reuse systems.

Step 1. Determine BMP Size

Permeable pavement must be sized to fully treat the desired or required design storm volume. Relevant regulatory requirements are presented in detail in Chapter 2. Aggregate pore space provides capacity for the design storm volume retention. Appendix A outlines methods for determining design runoff depths associated with a range of annual treatment efficiencies. Once the design runoff depth is determined (on the basis of the desired level of treatment), a runoff volume can be determined for the contributing watershed using this depth and the methods outlined in Appendix A, *San Antonio Unified Development Code*, or *San Antonio River Basin Regional Modeling Standards for Hydrology and Hydraulic Modeling*.

Peak flow rates for the design storm should also be calculated, using the methods outlined in Appendix A so that the inlet and pretreatment can be accordingly sized and flow attenuation can be considered.

Step 2. BMP Siting

Permeable pavement is a highly versatile stormwater BMP because it can effectively reduce pollutants and can be integrated into site plans with various configurations and components. Stormwater treatment should be considered as an integral component and incorporated in the site design and layout from conception. Many times, determining how permeable pavement will be included in the site design is a critical and required first step. How the water is routed to the permeable pavement and the available space will be key components in determining how the permeable pavement is configured. Site assessment, planning, and site design are discussed in detail in Section 1.6.

Permeable pavement is typically designed to treat stormwater that falls on the actual pavement surface area and has been used at commercial, institutional, and residential sites in spaces that are traditionally impervious. Outside the Edwards Aquifer Contributing Zone, Transition Zone, and Recharge Zone, runoff from adjacent surfaces is allowed but must be limited to runoff from stabilized areas with very little sediment yield. A maximum total drainage area to permeable pavement area ratio of 2:1 is recommended.

Runoff from pervious surfaces or high-sediment areas should be prevented, and permeable pavement should not be installed in areas prone to flooding with sediment-laden water (e.g., floodplains) because excessive sediment can prematurely clog the pores. Overhanging trees should also be avoided to reduce the deposition of detritus on the pavement surface, which can be ground into joints and pores if not routinely removed.

Because permeable pavements are intended for use in fully stabilized catchments, pretreatment measures are generally not required. An exception is presented if runoff is contributed to the permeable pavement from adjacent rooftops; leaves and debris should be screened before discharge onto the pavement surface.

Following is a list of settings in which permeable pavement can be incorporated to meet more than one project-level or watershed-scale objective:

- Parking lots
- Parking lanes in rights-of-way along roads
- Sidewalks and pedestrian plazas
- Access roads and shoulders

In addition, permeable pavement areas can be combined with other BMPs to form a treatment train that provides enhanced water quality treatment and reductions in runoff volume and rate. For example, runoff can flow from a roadway to the permeable pavement section and overflow to a bioretention area as shown in Figure B-3-1. Both facilities can be reduced in size according to demonstrated performance for meeting the stormwater runoff requirements as outlined in Chapter 2 and addressing targeted pollutants of concern.



Figure B-3-1. Permeable pavement and bioretention treatment train

Step 3. Select Permeable Pavement Surface Course

Several types of permeable pavement are available: pervious concrete, porous asphalt, permeable interlocking concrete pavers, concrete grid pavers, and plastic grid systems, among others. Each type of pavement has advantages and disadvantages, so factors such as cost, pavement use (parking area, driveway, sidewalk, fire lane, and such) and maintenance requirements should be considered on a site-by-site basis. When applicable, follow manufacturers' instructions to ensure a successful implementation.

Pervious concrete and porous asphalt are typically better suited for large parking areas. The advantage to those systems is that the same mixing and application equipment is used as for traditional asphalt and concrete. PICPs, grid pavers, and plastic grid systems are generally better suited to smaller areas because of the labor involved with installation; however, many contractors now employ mechanical placement technologies to expedite the installation of pavers making larger parking areas more feasible. PICP and block pavers can be used for driveways, entryways, walkways, or terraces to achieve a more traditional, formal appearance.

More detailed information for the various types of permeable pavement follow.

Porous Asphalt

Porous asphalt pavement consists of fine- and course-aggregate stone bound by a bituminous-based binder. The amount of fine aggregate is reduced to allow for a larger void space of typically 15 to 20 percent. Because porous asphalt is a hot-mixed pavement, binder temperature performance grade (PG) should be specified on the basis of the anticipated climate to prevent premature failure (melting and sealing) under extreme heat conditions. PG 76-22 liquid asphalt binder is

recommended (CAPA n.d.; TxDOT 2004). Thickness of the asphalt depends on the traffic load but usually ranges from 3 to 7 inches. A required underlying base course, typically a washed No. 57 stone, increases storage, and adds strength because porous asphalt is design to be a flexible pavement (Ferguson 2005). A 1- to 2-inch layer of choker course (single-sized crushed aggregate, one-half inch) is typically required to stabilize the surface. Porous asphalt with an aggregate reservoir layer is currently not approved by TCEQ to meet the TSS reduction criteria in the Edwards Aquifer rules (TCEQ 2012).

Porous asphalt can also be installed directly over existing concrete to form a permeable friction course (PFC) overlay. PFCs do not provide the volume storage capacity of porous asphalt systems with reservoir layers, but they can provide excellent water quality improvements in addition to enhanced driver safety (reduced hydroplaning, improved stopping distance, reduced spray, and improved visibility), noise reduction, and improved ride quality (Rand 2006; NCHRP 2009; Eck et al. 2012). PFC overlays have been used with great success on San Antonio and other Texas highways and have been approved to meet the TSS removal rules in the Edwards Aquifer (Rand 2006; TCEQ 2012). A typical porous asphalt profile is shown in Figure B-3-2.

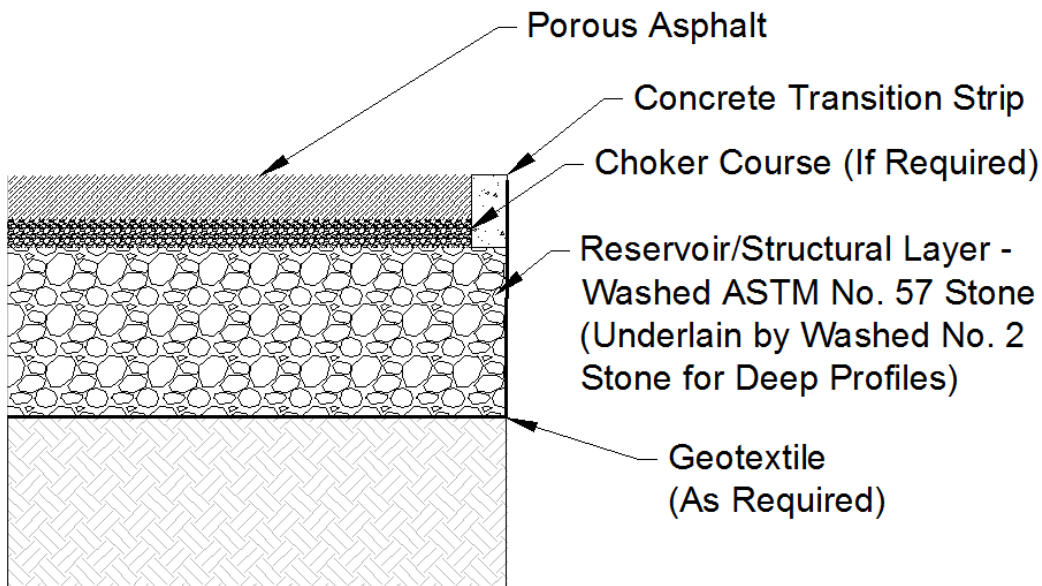


Figure B-3-2. Typical porous asphalt cross section

The properties of porous asphalt depend on the materials used and the compaction procedures. Specified mix design should be in accordance with the National Asphalt Pavement Association (NAPA) *Porous Asphalt Pavements for Stormwater Management* (NAPA 2008). General guidelines are provided below.

Permeability. Typical flow rates for water through porous asphalt range from 150 to 300 in/hr (Roseen and Ballesterro 2008). Those values exceed the typical permeability of subsurface soils, so the soils would be the limiting factor.

Aggregates. A typical aggregate size distribution for porous asphalt is below.

Appendix B.3 Permeable Pavement

Aggregate gradation size	Percent passing
0.75 inch	100%
0.50 inch	85%–100%
0.375 inch	55%–75%
No. 4	10%–25%
No. 8	5%–10%
No. 200	2%–4%

Durability. As with all BMPs, the longevity of porous asphalt (Figure B-3-3) is highly dependent on proper maintenance. Many porous asphalt parking lots have been in service for more than 20 years.



Figure B-3-3. Example of porous asphalt, Mission Library, San Antonio, Texas.

Pervious concrete is a mixture of Portland cement, fly ash, washed gravel, and water. The water-to-cementitious material ratio is typically 0.35–0.45 to 1 such that the mixture displays a wet metallic sheen without the paste flowing from the aggregate (NRMCA 2004; Barrett 2005). Unlike traditional installations of concrete, permeable concrete usually contains a void content of 15 to 25 percent, which allows water to infiltrate directly through the pavement surface to the subsurface. A fine, washed gravel, less than 13 mm in size (No. 8 or 89 stone), is added to the concrete mixture

to increase the void space (GCPA 2006). An admixture improves the bonding and strength of the pavements. The pavements are typically laid with a 4- to 8-inch (10 to 20 cm) thickness over a gravel reservoir (depth varies according to water volume capture requirements), typically a washed No. 57 stone. Pervious concrete is a rigid pavement and therefore does not require an aggregate base course for structural support. Pervious concrete will typically exhibit a coarser surface texture than impervious concrete but is ADA compliant. A typical pervious concrete profile is shown in Figure B-3-4.

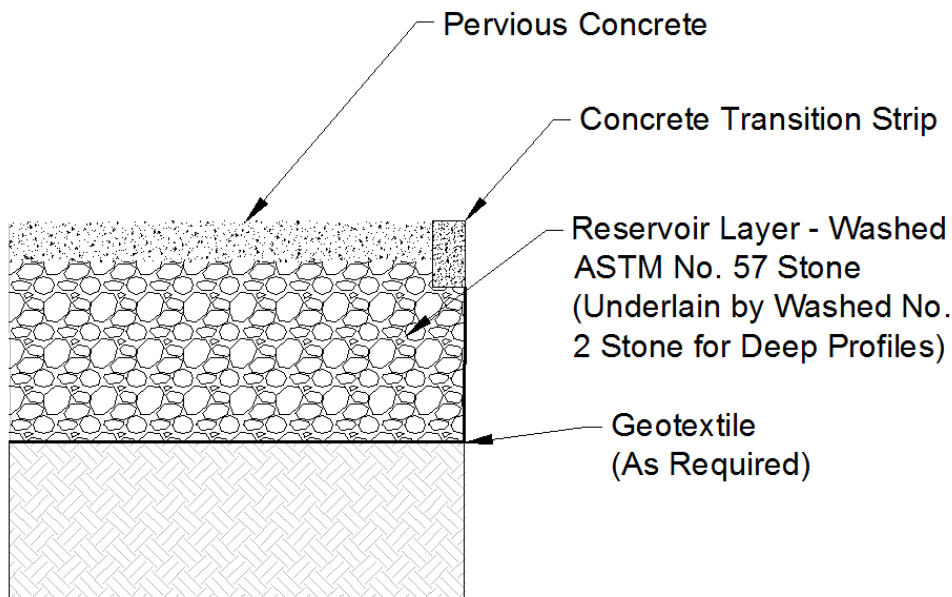


Figure B-3-4. Typical pervious concrete cross section

The properties of pervious concrete (Figure B-3-5) vary with design and depend on the materials used and the compaction procedures. Design mix should conform to the latest version of the American Concrete Institute’s ACI 522.1-08 *Specification for Pervious Concrete Pavements*. General guidelines for specifications are provided below.

Permeability. Typical flow rates through well-maintained pervious concrete average greater than 1,500 in/hr (Bean et al. 2007).

Compressive Strength. Pervious concretes can develop compressive strengths in the range of 500 to 4,000 pounds per square inch (psi)—suitable for a wide range of applications.

Flexural Strength. Flexural strength of pervious concrete ranges between 150 and 550 psi. Pervious concrete does not typically incorporate rebar.

Shrinkage. Drying shrinkage of pervious concrete is faster but much less than that experienced with conventional concrete. Pervious concretes should be constructed with control joints to regulate cracking. In general, joints should be cut one-quarter of the pervious concrete thickness, be placed a maximum of 20 feet on centers (15 feet is typical) perpendicular to the curb, and should form square panels.

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Abrasion resistance. Because of the rougher surface texture and open structure of pervious concrete, abrasion and raveling of aggregate particles can be a problem. Surface raveling in new pervious concrete can occur when rocks loosely bound to the surface break free under traffic loads. Such raveling is considerably reduced after the first few weeks. Raveling can be reduced by carefully covering the pervious concrete during curing to prevent the surface from drying prematurely. Polypropylene fibers and/or latex can also be added to reduce abrasion resistance (Dong et al. 2010).



Figure B-3-5. Example of pervious concrete, Kinston, North Carolina. Source: North Carolina State University Department of Biological and Agricultural Engineering

Permeable Interlocking Concrete Pavements

PICPs are available in many different shapes and sizes. When laid, the blocks form patterns that create openings through which rainfall can infiltrate. Orientation of rectangular pavers is important for structural purposes—*herringbone* patterns tend to provide the most efficient structural design, especially where vehicle stopping and turning are expected. ASTM C936-13 specifications state that the pavers be at least 2.36 inches (60 mm) thick with a compressive strength of 55 MPa (8,000 psi) or greater. Typical installations consist of the pavers and crushed aggregate fill, a 1.5- to 3.0-inch (38 to 76 mm No. 8) fine-aggregate bedding layer, and an aggregate base-course, typically a washed No. 57 stone, storage layer (Smith 2011). If greater storage is required, a reservoir subbase layer of No. 2 stone can be included. More details on PICP can be found in Smith (2011). An example PICP profile is shown in Figure B-3-6.

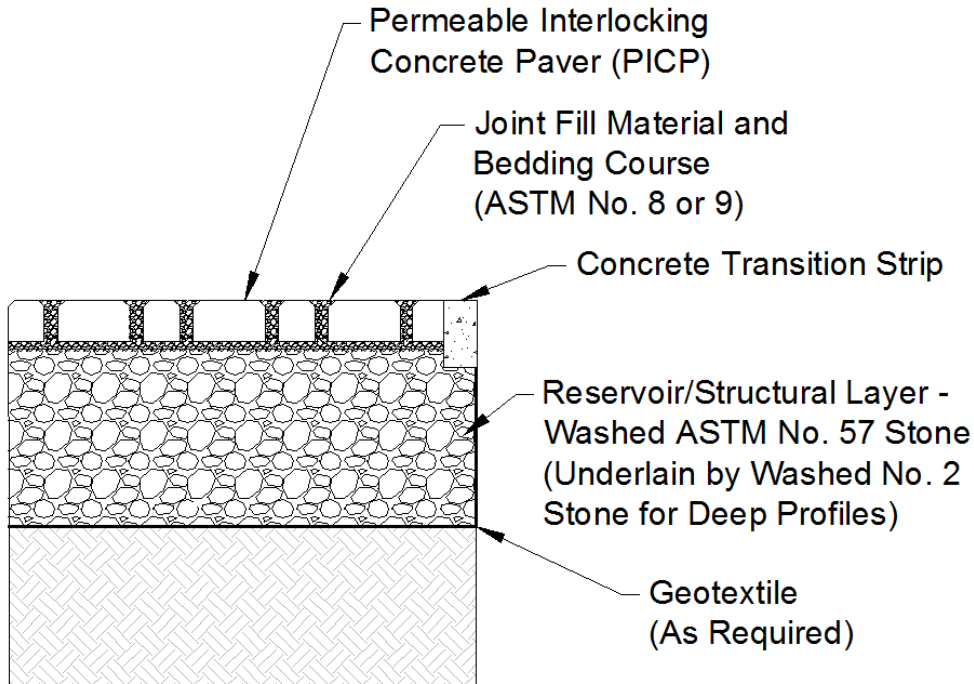


Figure B-3-6. Typical PICP cross section

Unlike permeable concrete and porous asphalt, PICP (Figure B-3-7) is not subject to time and temperature limitations in installation. Interlocking Concrete Pavement Institute (ICPI) standards should be followed during design and construction. Below are listed general specification guidelines.

Permeability. Lifetime infiltration rates on maintained PICP surfaces range from 14 to 4,000 in/hr depending on the joint filling material (Borgwardt 2006; Bean et al. 2007).

Compressive Strength. PICP has a minimum compressive strength of 8,000 psi (55 MPa).

Durability. Regularly maintained permeable pavement systems can last more than 20 years and provide an initial high level of surface infiltration even as the surface takes in moderate amounts of sediment.



Figure B-3-7. Example of Permeable Interlocking Concrete Pavers (PICP) in a herringbone pattern at San Antonio River Authority Main Office, San Antonio, Texas.

Concrete Grid Pavers

Concrete Grid Paver (CGP) systems conform to ASTM C 1319, *Standard Specification for Concrete Grid Paving Units* which describes paver properties and specifications. CGP units have a minimum thickness of 3.125 inches (80 mm) thick with a maximum 24 × 24 inch (60 × 60 cm) dimension. The percentage of open area ranges from 20 to 50 percent and can contain topsoil and grass, sand, or aggregate in the void space (Figure B-3-8). The minimum average compressive strength of CGP units can be no less than 35 MPa (5,000 psi). A typical installation consists of grid pavers with fill media, 1–1.5 inches (25 to 38 mm) of bedding sand or No. 8 gravel, gravel base course typically consisting of washed No. 57 stone, and a loosely compacted soil subgrade (ICPI 2004). If sand is used, a geotextile should be used between the sand course and the reservoir media to prevent the sand from migrating into the stone media.

The ICPI provides design standards for CGP design and installation, but application of CGPs is typically limited to very low traffic areas (such as emergency vehicle access roads or event overflow parking). This limitation is because of differential settling and subsequent *rocking* of pavers that can occur because CGPs (unlike PICP) do not interlock.



Figure B-3-8. Example of Concrete Grid Pavers (CGP) planted with turf grass that serves as an emergency vehicle access and landscape feature at the River House, San Antonio, Texas.

Plastic Grid Systems

Plastic grid systems, also called geocells, turf pavers, or turf reinforcing grids, consist of flexible-plastic, interlocking units that allow for infiltration through large gaps filled with gravel or topsoil planted with turf grass. Similar to PICP, a 1–2 inch sand bedding layer and gravel base course are often added to increase infiltration and storage. The empty grids are typically 90 to 98 percent open space, so void space depends on the fill media (Ferguson 2005). To date, no uniform standards exist; however, one product specification defines the typical load-bearing capacity of empty grids at approximately 13.8 MPa (2,000 psi) (Invisible Structures 2001). That value increases up to 38 MPa (5,500 psi) when filled with various materials (Invisible Structures 2001). If sand is used, a geotextile should be used between the sand course and the reservoir media to prevent the sand from migrating into the stone media. Plastic grid systems are currently not approved by TCEQ to meet the TSS reduction criteria in the Edwards Aquifer rules. A typical plastic grid system profile is shown in Figure B-3-9.

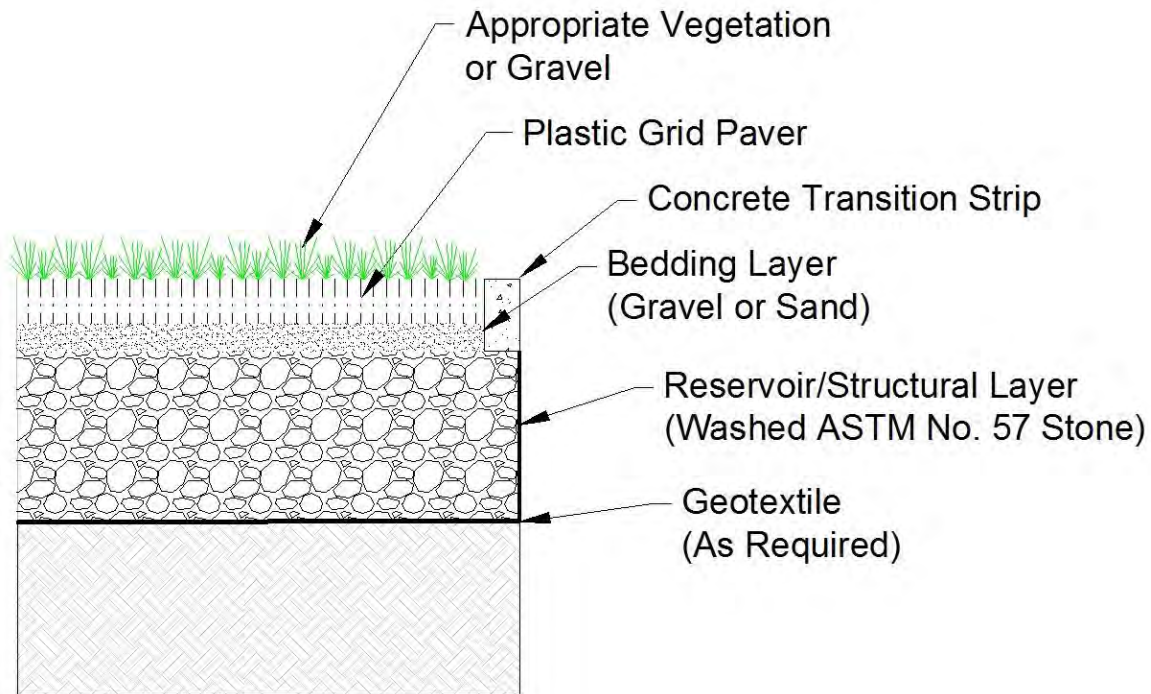


Figure B-3-9. Typical plastic grid system cross section

Plastic grids (Figure B-3-10) provide structural support but are generally limited to very low traffic areas such as emergency vehicle access lanes and event overflow parking. They are usually planted with grass. Several companies manufacture plastic grid systems.

Load bearing capacity. Plastic grid systems have a load-bearing capacity up to 6,700 psi when filled (CONTECH 2011).

Durability. Because plastic grid systems are typically manufactured from high-density polyethylene (HDPE), long service lives, up to 50 years, can be expected with proper maintenance.



Figure B-3-10. Example of plastic grid system filled with rock that serves as a roadway for residential units, San Antonio, Texas.

Step 4. Determine BMP Function and Configuration

The hydrologic and water quality performance of permeable pavement is largely determined by the drainage configuration. Furthermore, some areas might *not* warrant infiltration. The following design steps can be used to determine the drainage configuration design.

Perform Geotechnical Investigation

Once the appropriate surface course has been selected and discussed with the property owner, the in situ soils must be tested before the system can be sized. Performing soil tests during the conceptual and preliminary design phases will ensure that the proposed permeable pavement system is optimized to actual site conditions and to prevent costly change orders resulting from poorly estimated soil parameters.

A geotechnical investigation should be performed by a licensed soil scientist or geotechnical engineer. All soil testing should be performed at the depth of the initially proposed subgrade because this is the soil strata where infiltration might occur. If a detention (non-infiltrating system) is proposed, soil tests must still be performed to determine structural requirements and to identify the elevation of the seasonal high water table. For details on geotechnical analyses, see [Common Design Elements](#).

Determine if Underdrains and Impermeable Liners are Needed

On the basis of the infiltration rate measured in the previous step, the drawdown time of the system at full capacity should be calculated. If the infiltration rate of the soils on which the permeable pavement area will be installed is less than 0.5 in/hr, underdrains will be required (as described in Table B-3-2). The underdrains can be embedded in the aggregate reservoir layer or in a gravel trench below the reservoir layer, as shown in Figure B-3-11. For information on designing an underdrain system, see [Common Design Elements](#). IWS should be included in all infiltrating systems to enhance infiltration (Wardynski et al. 2013). The elevation of the upturned underdrain outlet dictates the volume of water retained in the profile, which should be greater than or equal to

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the water quality volume (as determined in [Step 5](#)). An example permeable pavement profile containing IWS is provided in Figure B-3-12.

If infiltration is disallowed, the system should be lined with a hydraulic restrictive layer. Factors prescribing an impermeable liner are provided in Figure B-3-2. Non-infiltrating systems are also known as detention systems and can be designed similar to other detention structures. Outflow should be regulated in accordance with water quality (releasing water over the course of 2 to 5 days) and flood control requirements for detention structures (discussed in [Step 6](#)).

Table B-3-2. Decision table for determining underdrain and impermeable liner requirements

Impermeable liners must be used if...	Underdrains must be used if...
<ul style="list-style-type: none"> Site is in Edwards Aquifer Recharge Zone or Transition Zone Soil contamination is expected or present Karst geology presents risk of sinkhole formation Runoff may unintentionally be received from a stormwater hotspot Site is within 100 feet of a water supply well or septic drain field Site is within 10 feet of a structure/foundation Infiltrated water may interfere with utilities 	<ul style="list-style-type: none"> An impermeable liner is needed Infiltration rate of underlying soils is less than 0.5 in/hr Site is within 50 feet of a steep, sensitive slope



Figure B-3-11. Permeable pavement showing example cross section with trenched underdrain at Alamo Heights Fire Station, Alamo Heights, Texas. Source: Tetra Tech

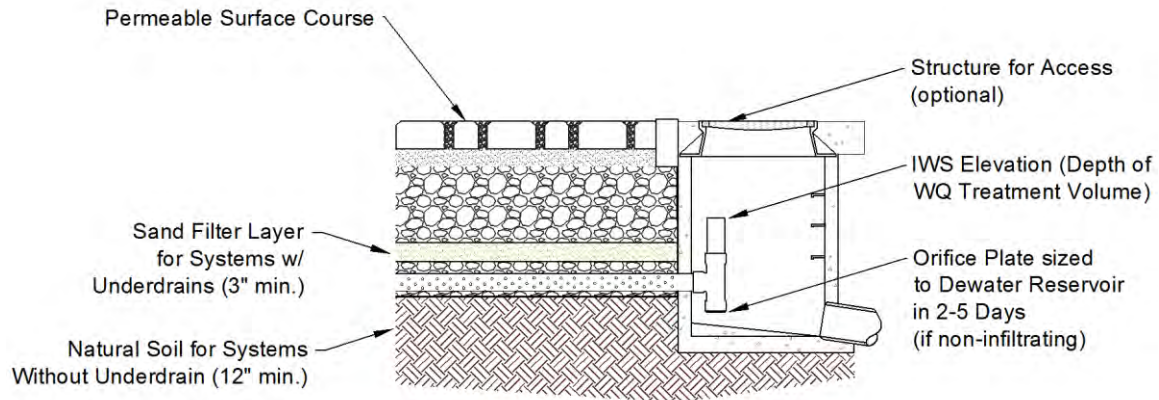


Figure B-3-12. Example permeable pavement profile featuring IWS

Observation Wells

Design drawings should specify installation of observation wells to monitor the drawdown rate of permeable pavement reservoir layers. Wells should be constructed of perforated PVC pipe (4-inch diameter or greater) and should be designed to prevent damage from vehicular traffic. If necessary, observation wells can be installed at an angle and daylight in adjacent landscape areas (as long as the well extends the full depth of the reservoir layer). Wells should be securely sealed with watertight caps. Figure B-3-13 provides examples of observation wells installed in permeable pavement applications.



Figure B-3-13. Observation well installed in permeable pavement

Design Subgrade Slope and Specify Geotextile

The subgrade slope should not exceed 0.5 percent to ensure that the design volume is captured and evenly distributed and to maintain structural integrity. Baffles can be installed along the subgrade to provide grade control if necessary. In fully lined systems, a drawdown orifice should be provided in each baffle to allow dewatering between storm events.

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A geotextile should be placed beneath the reservoir media and along the perimeter of the cut in all infiltrating systems. A needled, non-woven, polypropylene geotextile conforming to the specifications in Table B-3-3 should be specified. It is important to line the entire trench area, including the sides, with a geotextile before placing the aggregate. The geotextile serves an important function by inhibiting soil from migrating into the reservoir layer and reducing storage capacity.

Table B-3-3. Geotextile layer specifications

Geotextile property	Value	Test method
Grab tensile strength (lbs)	≥ 120	ASTM D4632
Mullen burst strength (lbs/sq. in.)	≥ 225	ASTM D3786
Permeability (gpm/sq. ft.)	≥ 125	ASTM D4491
Apparent opening size (sieve size)	#70–#80 (min)	ASTM D4751

*The geotextile apparent opening size selection is based on the percent passing the No. 200 sieve in A Soil subgrade, using FHWA or AASHTO selection criteria.

Step 5. Design the Profile

The permeable pavement profile must be designed to capture the water quality treatment volume and filter it through soil or a sand filter layer. In fully lined (non-infiltrating systems), the treatment volume should ideally be detained for 2 to 5 days (orifice sizing equations are in the [Stormwater Wetlands](#) section). Additionally, the profile must provide structural support for the anticipated vehicular loading.

Temporary Surface Ponding Depth (Edwards Aquifer Zones)

When permeable pavement is used in the Edwards Aquifer protection zones, surface ponding must be provided (by curb and gutter) such that the design storm volume will be retained onsite if the permeable pavement surface clogs (Barrett 2005). Curb edging and driveways should be elevated such that the design water quality volume ponds on the surface and does not flow offsite. This is not typically a requirement outside the Edwards Aquifer protection zones.

Specify Sand/Soil Filter Layer

Percolating runoff through native soils is the most effective way to improve water quality. When no underdrains are required (when subsoil infiltration rates greater than 0.5 in/hr), a minimum of 12 inches of native soil should be provided at the subgrade to filter captured stormwater before infiltration (for soil specifications, see [Common Design Elements](#)). If underdrains are used, or if subsoils are not suitable for stormwater filtration, a minimum of 3 inches of ASTM C-33 washed sand should be included above the aggregate of the underdrain drainage layer. A layer of choking stone might be needed between the sand filter layer and the gravel drainage layer, as discussed in [Common Design Elements](#).

Calculate Surface Area and Reservoir Media Depth

The aggregate base course should be designed to store at a minimum the water quality treatment volume determined in Appendix A. For infiltrating systems, this volume should be retained in the profile using IWS (as described in step 4). The stone aggregate used should be washed, angular, crushed stone, 0.75 to 2.5 inches in diameter with a void space of about 40 percent (No. 57 stone). ASTM No. 2 stone may be used as a subbase layer below the base course for additional storage.

Aggregate contaminated with soil and typical *crusher run* stone should not be used because those materials will clog the pores at the bottom of the pavement.

If the area of permeable pavement is known, the following equation can be used to determine the depth of storage layer (aggregate base course) needed to capture the water quality treatment volume:

$$d = \frac{V}{An} \quad \text{[Equation B-3-1]}$$

where:

d = aggregate layer depth (ft)

V = water quality volume (ft³)

A = surface area (square ft)

n = porosity (use actual laboratory measured porosity of material)

Structural Design Requirements

If permeable pavement will be used in a parking lot or other setting that involves vehicles, the pavement surface must be able to support the maximum anticipated traffic load. The structural design process will vary according to the type of pavement selected, and the manufacturer's specific recommendations should be followed. The thickness of the permeable pavement and reservoir layer must be sized to support structural loads and to temporarily store the design storm volume (e.g., the water quality, channel protection, and flood-control volumes). On most new development and redevelopment sites, the structural support requirements will dictate the depth of the underlying stone reservoir.

The structural design of permeable pavements involves considering four main site elements:

- Total traffic
- In situ soil strength
- Environmental elements
- Bedding and reservoir layer design

The resulting structural requirements can include the thickness of the pavement, filter, and reservoir layer. Designers should note that if the underlying soils have a low California Bearing Ratio (less than 4 percent), the soil might need to be compacted to at least 95 percent of the Standard Proctor Density, which generally rules out their use for infiltration.

Designers should determine structural design requirements by consulting transportation design guidance sources, such as the following:

- AASHTO Guide for Design of Pavement Structures (1993)
- AASHTO Supplement to the Guide for Design of Pavement Structures (1998)

Step 6. Design for Safe Bypass/Conveyance of Large Storms

Permeable pavement systems, as with any other stormwater BMP, must be designed to safely route runoff in excess of the intended design flow. The method of large-storm routing is largely site

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specific and depends on the type of permeable surface course. When poured in place, surface courses are used (pervious concrete or porous asphalt), volume in excess of the system storage capacity can be allowed to bubble up through the profile and run off the site safely as surface flow. Catch basins or slot drains could be installed around the perimeter of the permeable pavement to drain any overflow; inlets can be specified slightly above the elevation of the finished surface to allow some surface ponding, if allowable.

Modular paving systems (PICP, CGP, or plastic grid systems) should *not* be designed to overflow in this manner, however, because upflowing water could dislodge and carry away aggregate from the bedding course. When surface overflow is not a feasible or preferred option, the system can be designed to (1) completely store the 25-year storm volume in the aggregate reservoir and exfiltrate into underlying soils, (2) convey larger storms safely through the system using underdrains (equipped with orifices, if required), or (3) use other internal controls to allow bypass of larger storms. Large storm routing can be designed to satisfy detention requirements, per local requirements (see Chapter 2).

Step 7. Design Edge Restraints and Transitions

Providing separation between permeable pavements and adjacent impermeable surfaces serves multiple purposes, including the following:

1. Clearly identifying for maintenance personnel the transition between permeable and impermeable surfaces
2. Restraining modular (block) pavers and porous asphalt to prevent lateral shifting or unraveling of edges
3. Creating a hydraulic restriction layer to prevent lateral seepage of runoff below adjacent pavements and structures
4. Delineating parking zones with clean, aesthetically pleasing lines

Restraints for flexible pavements are typically composed of standard concrete curbs (elevated or at grade, depending on application) or specially designed monolithic concrete walls. At intersections between permeable and impermeable surfaces, a hydraulic restriction layer (typically a geomembrane) is installed along the entire length of the cut and at least 2 feet laterally along the subgrade and under the *impermeable* surface. Figure B-3-14 shows an example of an edge restraint.



Figure B-3-14. A 1-foot concrete transition strip is used as an edge restraint between PCIP and impermeable asphalt, Floresville, Texas.

Step 8. Design Signage

It is good practice to specify signage on engineering plans; signage educates the public and identifies permeable pavements to maintenance personnel. Prohibited practices, such as stockpiling soils or mulch, should be clearly displayed to protect permeable pavements from premature clogging. Signage will also prevent poured in place permeable pavements from being mistaken as impermeable and then paved over during repair.

Step 9. Design for Multi-Use Benefits

Permeable pavements inherently provide multi-use benefits because the facilities double as parking lots and transportation corridors. In addition to these benefits, permeable pavement can be enhanced by incorporating the following design elements:

- Enhanced pavement textures, colors, and patterns can calm traffic, increase aesthetic appeal, enhance pedestrian safety, and draw attention to multi-use stormwater practices.
- Stormwater reuse systems can be installed to harvest and use captured runoff for non-potable use (irrigation, ornamental water features, and such).
- Permeable pavers can be used to maintain the character of historic districts while providing stormwater management solutions.

Educational kiosks and signage raise public awareness of stormwater issues.

B.3.2 Critical Construction Considerations

Notes on construction plans should specify that tracked vehicles (versus wheeled vehicles) be used whenever practicable to minimize compaction of subsoils. Construction specifications should also include notes requiring the testing of subgrade infiltration rates before installing aggregate (for infiltrating systems). This step ensures that captured water will draw down in the required duration. If subgrade infiltration rates are drastically lower than design values, the subgrade should be treated by scarifying, ripping, or trenching according to the recommendations in [bioretention](#). If infiltration rates remain lower than required, the profile depth must be changed to provide additional storage or the drainage configuration must be altered to regulate the drawdown.

Careful inspection of several construction steps can prevent costly errors. Construction of permeable pavement systems should be performed only by a contractor with experience in permeable pavement installation and that is certified by the Interlocking Concrete Pavement Institute or the National Ready Mix Concrete Association. Lists of certified contractors are at <https://www.icpi.org/> or <http://www.nrmca.org>. In addition to the general considerations in Chapter 4, the following practices should be completed by the designer or a trained inspector.

B.3.2.1 Inspect Aggregate Upon Delivery

Stone aggregate bedding, base, and subbase courses should be thoroughly washed to prevent fines from clogging the subsoil interface or underdrains (Fassman and Blackbourne 2010). Before placement, the furnished aggregate should appear free of fines and leave no substantial dust on the skin when handled. Unwashed aggregate should be replaced or washed onsite using proper construction site sediment control practices.

B.3.2.2 Inspect Elevations

Elevation discrepancies during grading or placing pipe inverts can result in undersized (and underperforming) systems. Verifying the average subgrade elevation and the elevation of the outlet invert will help ensure that the specified reservoir storage volume has been provided.

B.3.2.3 Test Actual Subgrade Infiltration Rate

After excavation and before installing aggregate, the actual in situ infiltration rate should be measured using the methods in [Common Design Elements](#). This is a critical step to determine the level of compaction experienced during construction so that adequate mitigation practices can be recommended.

B.4.2.4 Mitigate Soil Compaction to Enhance Exfiltration

If exfiltration rates (as determined in previous step) are substantially lower than design values, the subgrade should be treated according to Table B-3-4 to mitigate compaction. If subgrade exfiltration rates are substantially lower than original design rates, it may be necessary to provide additional aggregate reservoir depth to accommodate storage and exfiltration of subsequent rainfall events.

Table B-3-4. Subgrade treatments for infiltration enhancement

Subgrade compaction	Minimum subgrade treatment	Specification
Low	Scarification	Loosen the top 6 to 9 inches of subgrade using the teeth of an excavator bucket (or comparable). This can be achieved by excavating the final 1 foot using a toothed bucket.
Low-Medium	Ripping	Using a subsoil ripper or metal bar, rip the subgrade to a depth of 9 to 12 inches, every 3 feet (on center). When operating in silty, loamy, or clay soils, fill ripped areas with coarse sand to maintain free-flowing trenches.
High	Trenching	Excavate 1-foot-deep by 1-foot wide trenches into the subgrade, every 6 feet (on center). Fill the bottom of the trench with one-half inch of coarse sand, and top off trench with washed aggregate (No. 57 stone or comparable).

B.3.2.5 Inspect Surface Course Placement and Curing

Poured in place surface courses should be inspected during placement to ensure proper mix characteristics. After screeding and compaction, inspectors should ensure that the surface of pervious concrete is not smeared (particularly when placing plastic over the surface for curing).

B.3.3 Operation and Maintenance

Maintenance of permeable pavement systems is critical to the overall and continued success of the system. Specific maintenance activities are listed in Table B-3-5. Key maintenance procedures consist of the following:

1. Adjacent areas that drain to the permeable pavement area should be permanently stabilized and maintained to limit the sediment load to the system.
2. Vacuum sweeping should be typically performed a minimum of twice a year. Adjust the frequency according to the intensity of use and deposition rate on the permeable pavement surface.
3. Any weeds that grow in the permeable pavement should be sprayed with pesticide immediately. Weeds should not be pulled, because doing so can damage the fill media.
4. Mowing and trimming turf grass used with permeable pavers and plastic grid systems must be performed regularly according to site conditions. Grass should be mowed at least once a month in the growing season. All vegetated areas must be inspected at least annually for erosion and scour.

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Table B-3-5. Operation and maintenance tasks for permeable pavement

Task	Frequency	Indicator maintenance is needed	Maintenance notes
Catchment inspection	Weekly or biweekly during routine property maintenance	Sediment accumulation on adjacent impervious surfaces or in voids/joints of permeable pavement	Stabilize any exposed soil and remove any accumulated sediment. Adjacent pervious areas might need to be graded to drain away from the pavement.
Miscellaneous upkeep	Weekly or biweekly during routine property maintenance	Trash, leaves, weeds, or other debris accumulated on permeable pavement surface	Immediately remove debris to prevent migration into permeable pavement voids. Identify source of debris and remedy problem to avoid future deposition.
Preventative vacuum/regenerative air street sweeping	Twice a year in higher sediment areas	N/A	Pavement should be swept with a vacuum power or regenerative air street sweeper at least twice per year to maintain infiltration rates.
Replace fill materials	As needed	For paver systems, whenever void space between joints becomes apparent or after vacuum sweeping	Replace bedding fill material to keep fill level with the paver surface.
Restorative vacuum/regenerative air street sweeping	As needed	Surface infiltration test indicates poor performance or water is ponding on pavement surface during rainfall	Pavement should be swept with a vacuum power or regenerative air street sweeper to restore infiltration rates.

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B.4 Planter Boxes



Rendering of example planter box retrofit to treat rooftop runoff at Sunset Station. San Antonio, Texas.

B.4.1 Design

Planter boxes provide similar function to a bioretention area but can be used to provide treatment where infiltration is not possible because of geotechnical limitations or vertical constraints. The design process is similar to that of lined (non-infiltrating) bioretention cells with a few noted exceptions in Table B-4-1.

Table B-4-1. Iterative design process

Design step	Design component/ consideration	General specification
1 Determine BMP Treatment Volume (B-75)		Use Appendix A
2 BMP Siting (B-75)		Based on available space, incorporate along the perimeter of buildings, along the roadway right-of-way, or near the outlet of a green roof or cistern.
3 Determine BMP Function and Configuration (B-76)	Impermeable liner	Planter boxes are typically contained in a concrete vault (as described in Common Design Elements)
	Underdrain (required)	Schedule 40 PVC pipe with perforations (slots or holes) every 6 inches. 4-inch diameter lateral pipes should join a 6-inch collector pipe, which conveys drainage to the downstream storm network. Provide cleanout ports/observation wells for each underdrain pipe at spacing consistent with local regulations. See Common Design Elements
	Internal water storage (IWS)	With careful plant selection, the outlet can be slightly elevated to create a sump for additional moisture retention to promote plant survival and enhanced treatment. Top of IWS should be more than 18 inches below surface.
4 Size the System (B-76)	Temporary ponding depth	6-18 inches (6-12 inches near schools or in residential areas); average ponding depth of 9 inches is recommended
	Soil media depth	2-4 feet (deeper for better pollutant removal, hydrologic benefits, and deeper rooting depths)
	Surface area	Find surface area required to store treatment volume in temporary ponding depth, soil media depth, and gravel drainage layer depth (media porosity ≈ 0.35 and gravel porosity ≈ 0.4)
5 Specify Soil Media (B-76)	Composition and texture	85-88% sand, 8-12% fines, 2-5% plant-derived organic matter (animal wastes or by-products should never be applied)
	Permeability	1-6 in/hr infiltration rate (1-2 in/hr recommended)
	Chemical composition	Total phosphorus < 15 ppm, pH 6-8, CEC > 5 meq/100 g soil
	Drainage layer	Separate soil media from underdrain with 2 to 4 inches of washed sand, followed by 2 inches of choking stone (ASTM No. 8) over a 1.5 foot envelope of ASTM No. 57 stone.
6	Inlet	Provide stabilized inlets (see Common Design Elements)

Design step	Design component/ consideration	General specification
Design Inlet and Pretreatment (B-76)	Pretreatment	Minimal pretreatment is required if receiving rooftop runoff; however, pretreatment recommendations provided in bioretention section should be followed if receiving surface runoff from paved areas.
7 Select and Design Overflow/Bypass Method (B-77)	Outlet configuration	Online: All runoff is routed through system—install an elevated overflow structure or weir at the elevation of maximum ponding Offline: Only treated volume is diverted to system—install a diversion structure or allow bypass of high flows
	Peak flow mitigation	Provide additional detention storage and size an appropriate non-clogging orifice or weir to dewater detention volume
8 Select Mulch and Vegetation (B-78)	Mulch	Dimensional chipped hardwood or triple shredded, well-aged hardwood mulch 3 inches deep.
	Vegetation	See Plant List (Appendix E)
9 Design for Multi-Use Benefits (B-78)	Include features to enhance habitat, aesthetics, public education, and shade.	

Step 1. Determine BMP Treatment Volume

The planter box must be sized to fully capture the desired or required design storm volume and filter it through the soil media. Relevant regulatory requirements are presented in detail in Chapter 2. Surface storage (in the ponding area) and soil pore space (in the plant rooting zone and the underlying media and gravel drainage layers) provide capacity for the design storm volume retention. The volume of water that must be treated is equal to the design storm volume and can be calculated using the information in Appendix A. Once the design runoff depth is determined (according to the desired level of treatment), a runoff volume can be determined for the contributing watershed using this depth and the methods outlined in Appendix A, *San Antonio Unified Development Code*, or *San Antonio River Basin Regional Modeling Standards for Hydrology and Hydraulic Modeling*.

Peak flow rates for the design storm should also be calculated, using the methods outlined in Appendix A, so that the inlet and pretreatment can be accordingly sized and flow attenuation can be considered.

Step 2. BMP Siting

Planter boxes, like bioretention areas, can be incorporated into the site design with various configurations and components. Unlike bioretention areas, planter boxes, because they are completely contained, can be included close to buildings and other structural foundations without affecting structural stability as long as underdrain outflow and overflow are routed in a safe direction. Planter boxes can be *perched* above grade on structures and/or be placed in series along a grade (tiered systems) to take advantage of vertical structures.

Appendix B.4 Planter Boxes

Step 3. Determine BMP Function and Configuration

Planter boxes have the same drainage requirements as [bioretention](#) but are typically hydraulically isolated from subsoils so underdrains are always required. IWS is not generally incorporated into planter box design unless a very shallow reservoir is provided. Care must be taken to select plants that can withstand saturated root zones if IWS is selected as a design option.

Step 4. Size the System

Planter boxes have the same sizing standards as a [bioretention](#) area.

Step 5. Specify Soil Media

Planter boxes must meet same soil media standards as a [bioretention](#) area.

Step 6. Design Inlet and Pretreatment

Inlets for a planter box must meet the same standards as inlets for [bioretention](#) area. Planter boxes can incorporate filter strips, forebays, and curb cuts if located along the right-of-way. Because of the ability to install planter boxes adjacent to structural foundations, a planter box inlet can also incorporate a downspout from an adjacent building. Pipe flow and downspouts can be stabilized using similar strategies for a curb cut using sod, if the flow rate is less than 3 cubic feet per second (cfs), stone, splash block, or other erosion protection material for higher flows. Alternatively, downspouts can be upturned to *bubble up* into the planter box in a diffuse manner. A potential inlet configuration is shown in Figure B-4-1 and Figure B-4-2.



Figure B-4-1. Planter box inlet configuration, San Diego, California. Source: Tetra Tech

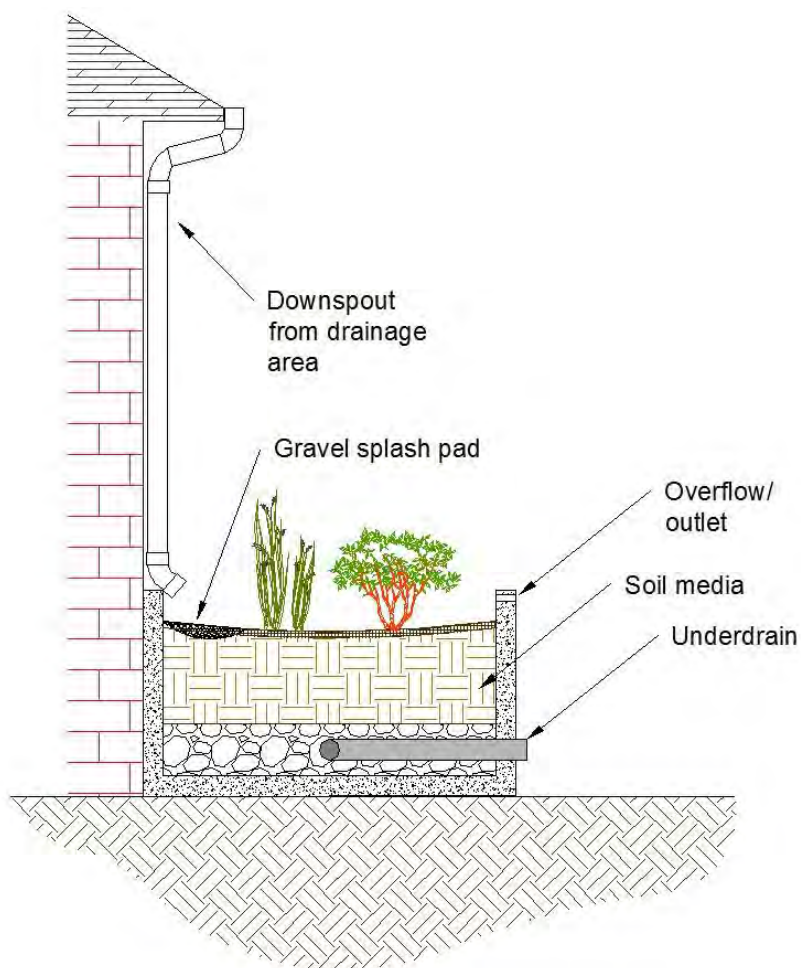


Figure B-4-2. Planter box inlet configuration

Step 7. Select and Design Overflow/Bypass Method

Planter boxes can be designed as offline or online systems. Planter boxes designed in the right-of-way should be designed as offline systems. Because underdrains will be required for planter boxes, the overflow system will typically include a vertical riser in both online or offline systems. The vertical riser should be designed as described in the [bioretention](#) section. Figure B-4-3 shows an example of a planter box with a vertical riser.

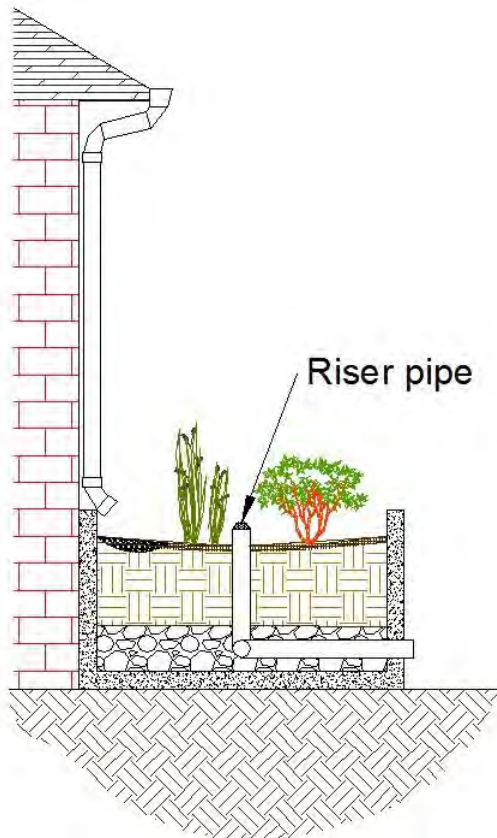


Figure B-4-3. Schematic of planter box with vertical riser

Step 8. Select Mulch and Vegetation

The mulch and vegetation will be the same for a planter box as a [bioretention](#) area. Some consideration should be taken as to the location of the planter box when selecting the vegetation. Shade-tolerant plants should be selected if the planter box will be shaded by surrounding structures. Planter boxes in the right-of-way should be vegetated with low shrubs to comply with sight distance requirements.

Step 9. Design for Multi-Use Benefits

Planter boxes can fulfill similar multi-use benefits as [bioretention](#) areas, but they can be more adaptable to highly impervious urban landscapes.

B.4.2 Critical Construction Consideration

The same construction considerations for [bioretention](#) should be employed in constructing planter boxes, except subgrade compaction does not require mitigation. In fact, depending on the weight of the planter box, aboveground systems might require a gravel or concrete footer to distribute the load (see foundation requirements in [Cisterns](#)).

B.4.3 Operation and Maintenance

Planter boxes require the same operation and maintenance as a bioretention area. For appropriate operation and maintenance, see [Bioretention](#).

B.5 Green Roofs



Intensive green roof that serves as a patio space at the Center for Science and Innovation. Trinity University, San Antonio, Texas.

B.5.1 Design

Green roof design is largely dependent on structural constraints of the subject and desired goals. Table B-5-1 summarizes the nine basic design steps, which are described in more detail below. Additional design guidance can be found in Tolderlund (2010) and New York City Department of Environmental Protection and New York City Department of Buildings (2012).

Table B-5-1. Iterative design step process

Design step		Design component/ consideration	General specification
1	Determine Green Roof Type (B-81)	Extensive	Shallow growing media (4–6 inches), small, drought-tolerant vegetation, no irrigation needed.
		Intensive	Growing media more than 6 inches, regular irrigation required deeper rooted vegetation. Contact qualified professional with experience designing intensive green roofs.
2	Determine Green Roof Size (B-83)	Use Appendix A	
3	Determine Structural Capacity of Roof (B-83)	Underlying roof deck and building structure	Evaluate proposed or existing building and roof structure to determine additional dead and live load capacity available to accommodate green roof installation
4	Specify Impermeable Liner and Root Barrier (B-83)	Roof liner	Select waterproof liner. Conventional roof waterproofing tar is typically sufficient but can be supplemented with waterproof geomembranes if desired.
		Root barrier	Select root barrier. Geomembranes used as waterproof liners can sometimes double as root barriers.
5	Specify Drainage Layer (B-84)	Aggregate	Minimum 2 inches of clean washed No. 8 stone or alternative lightweight, high-porosity, inorganic or synthetic aggregate. Geotextile fabric should be installed between the media and the aggregate.
		Manufactured	Select drainage layer specified for green roof applications that incorporates minimum 0.75 inch of retention storage of rainfall. Geotextile fabric should be installed between the media and the drainage layer.
6	Design Outlet Components (B-84)	Roof drains	Provide roof drains or scuppers consistent with local building code requirements. Surround outlets with minimum 12 inches of high-porosity drainage material (washed ASTM No. 57 stone or comparable)
7	Specify Soil Media (B-85)	Depth	Minimum 4-inch depth (intensive green roofs)
		Content	Media should consist of a well-drained, high-porosity mix of primarily lightweight aggregate (preferred media is site specific, but expanded mineral materials are typically specified for intensive green roofs). pH = 6.5–8.0, CEC greater than 10 meq/100 g.
8	Select Vegetation (B-86)	Low growing, drought-tolerant species	See plant list in Appendix E

Design step		Design component/ consideration	General specification
9	Design for Multi-Use Benefits (B-86)	Site specific	Include features to enhance recreational opportunities, habitat, aesthetics, and energy savings.

Step 1. Determine Green Roof Type

Green roofs can be categorized into one of two basic types according to design goals, structural constraints, and funding: extensive and intensive. The following subsections describe each type of green roof.

Extensive Green Roofs

Green roofs with less than 6 inches of media and shallow-rooting, xeric vegetation are considered extensive (Figure B-5-1). These roofs require little or no irrigation and contribute lighter loads to rooftops than intensive green roofs. Vegetation is typically composed of small succulents like stonecrops (*Sedum* spp.) or other desert plants that can withstand extreme temperature and moisture fluctuations. In the semi-arid environment, extensive green roofs typically require drip irrigation during plant establishment and dryer summer months. Irrigation should be achieved using air conditioner condensate or harvested rainwater. If sufficient water is not available from these sources, deeper media with higher water holding capacity can be specified or an alternative BMP should be selected. Various manufactured systems are available on the market with modular trays and built-in drainage layers to simplify design and installation.



Figure B-5-1. Example of an extensive green roof, East Lansing, Michigan. Source: Tetra Tech

Intensive Green Roofs

When a green roof has more than 6 inches of media and features deeper-rooting plants, it is considered intensive (Figure B-5-2). Intensive green roofs can be installed where structural support can handle the extreme weight of deep, saturated soils and vegetation. Often intended to function as small rooftop parks or gardens, intensive green roofs can provide many amenities; however, park-like landscaping on a rooftop might require irrigation, so take care to select water-efficient plants, especially if limited air conditioner condensate is available (Bexar Regional Watershed Management will not support BMPs that require permanent irrigation systems). Because of the wide variability in intensive green roof layout, media type and depth, irrigation demand and landscaping, it is not appropriate to explore the design process in this manual. For more design guidance, contact a qualified professional with experience in implementing intensive green roofs.



Figure B-5-2. Example of an intensive green roof at James Madison High School Agriscience Building, San Antonio, Texas. Source: Bender Wells Clark Design

Step 2. Determine Green Roof Size

Green roofs typically treat only direct rainfall, except for certain situations where runoff is generated from adjacent roof areas or where air conditioner condensate is captured. Design volume and flow rates can be determined using the methods in Appendix A.

Step 3. Determine Structural Capacity of Roof

Green roof design primarily depends on the excess load that can be applied to a rooftop. **A qualified structural engineer should be consulted to determine the structural capacity of the roof in question to support additional dead and live load resulting from green roof installation.** For new construction, the building designer might consider the additional roof load in selecting building structural components. In either scenario the dead and live roof loads from the green roof installation will depend on the specific green roof components and must be evaluated case by case. In general, extensive green roofs can be expected to exert a dead load (fully saturated) of 15 lb/square foot to 55 lb/square foot. Loading by intensive green roofs will widely vary based on soil depth and other components (Tolderlund 2010).

Step 4. Specify Impermeable Liner and Root Barrier

As with all roofs, a watertight barrier must be provided to prevent rainwater from infiltrating the underlying structure. Watertight tar surfaces (conventionally used for roof sealing) are usually

Appendix B.5 Green Roofs

sufficient impermeable liners, but additional plastic or rubber membranes can be placed over the tar for added protection. The liner should be resistant to heat, desiccation, and ultraviolet radiation. A root barrier should be specified and placed directly above the impermeable liner or alternatively above an optional insulation layer that can be placed directly on the liner.

Step 5. Specify Drainage Layer

A drainage layer, also known as a drainage net or sheet drain, is necessary to convey excess rainwater to the roof drains. This layer will also maintain an aerobic root zone for plant health. Geotextile should be placed between the media and the drainage layer to prevent migration of media and act as a root barrier. Geotextiles containing chemicals that prevent root penetration can be used so root systems do not infiltrate and clog the drainage layer. A typical green roof cross section is shown in Figure B-5-3.

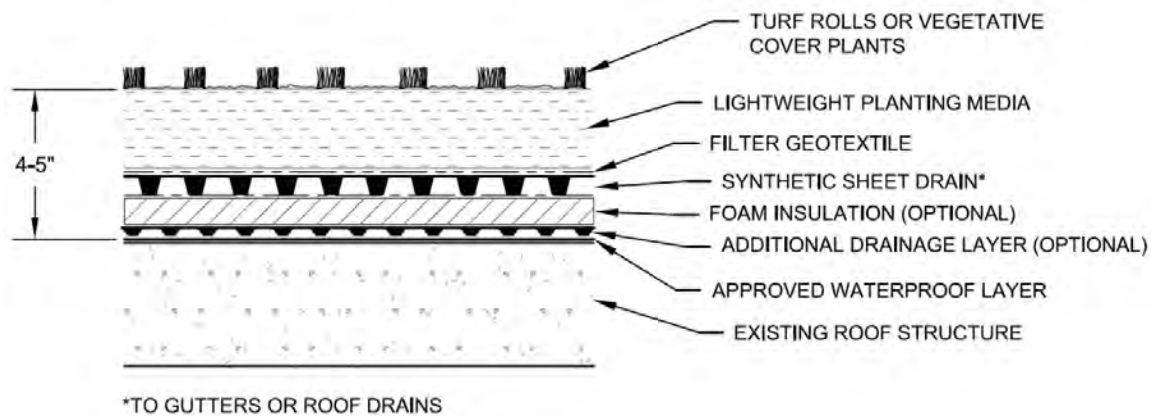


Figure B-5-3. Typical extensive green roof profile

Step 6. Design Outlet Components

As with all roofs, components must be incorporated into the roof structure to allow free drainage of excess runoff from the rooftop and away from the building. For extensive green roof applications, drainage components can include internal roof drains or roof scuppers along roof perimeters. These components should be designed in accordance with local building codes. To ensure adequate conveyance of roof runoff from the drainage layer to the outlets, green roofs should be set back a minimum of 12 inches from roof drains. The area surrounding the roof drains should be filled with clean washed No. 57 stone or alternative high-porosity material. Placing light-colored stone buffer around the roof drains also delineates a *no-plant zone* for maintenance staff (Figure B-5-4). The no-plant zone should remain free of vegetation to prevent drain clogging.



Raleigh, North Carolina. Source: Amy Hathaway, City of Raleigh

Figure B-5-4. Light-colored gravel delineates the no-planting zone for maintenance personnel, Raleigh, North Carolina. Source: City of Raleigh

Step 7. Specify Soil Media

Green roofs can be designed as flow-through systems or can be designed to detain a specific design volume of water (as determined by a qualified structural engineer). Sizing methodology presented in [Bioretention](#) can be used to design the system to capture a specific design volume. Soil media for green roofs should have the following characteristics:

- Well drained and aerated
- High porosity
- High nutrient holding capacity (cation exchange capacity)
- Permanent (non-biodegrading)
- Lightweight
- Windproof
- Stable (must support plants)

Several media types are available from green roof component suppliers, but generally expanded lightweight aggregates are preferred (e.g., expanded slate, expanded shale, expanded clay, terra cotta). For extensive green roofs, a minimum of 4 inches of media should be provided. The specifications provided in Table B-5-2 are example parameters that should be specified on design plans. Intensive green roofs should also employ lightweight aggregate media, but structural capacity generally allows a wider range of soil materials. Green roof media installation can be challenging and may require the use of a crane, auger, conveyor, or pneumatic delivery system.

Table B-5-2. Example of green roof media specifications

Parameter	Specification
Non-capillary pore space at field capacity	15% (vol)
Moisture content at field capacity	12% (vol)
Maximum media water retention	30% (vol)
Alkalinity, Ca CO ₃ equivalents	2.5%
Total organic matter by wet combustion	3-15% (dry wt.)
pH	6.5-8.0
Soluble salts	6 mmhos/cm
Cation exchange capacity	10 meq/100g
Saturated hydraulic conductivity for single media assemblies	0.05 in/min
Clay fraction (2 micron)	0
Pct. passing US#200 sieve (i.e., silt fraction)	5%
Pct. passing US#60 sieve	10%
Pct. passing US#18 sieve	5%–50%
Pct. passing 1/8-inch sieve	20%–70%
Pct. passing 3/8-inch sieve	75%–100%

Step 8. Select Vegetation

Green roof vegetation should consist of low-growing, highly drought-tolerant, biodiverse species that are adapted to survive in the harsh environment of a rooftop. Appropriate vegetation should be selected based on the specific site conditions and recommendations by local horticulturalists and green roof manufacturers.

Step 9. Design for Multi-Use Benefits

Green roofs can provide benefits to the urban environment in which they are placed. In various studies they have been shown to increase property values, reduce energy use, reduce heat island effect, increase roof lifespan, reduce air pollution, and enhance the health of adjacent property owners. Studies evaluating the multi-use benefits of green roofs are listed in Chapter 3.



Figure B-5-5. Green roof that provides educational and recreational opportunities at James Madison High School Agriscience Building, San Antonio, Texas. Source: Bender Wells Clark Design

B.5.2 Critical Construction Considerations

Green roofs inhabit a unique location in the urban landscape that results in designers facing construction considerations that are not applicable to landscape-based BMPs.

B.5.2.1 Provide Access for Installation, Inspection, and Maintenance

During construction, green roof materials must be transported to the rooftop. This can be done via ladder lifts, elevators, or human physical labor; the most efficient method is typically using a crane. Media can be pneumatically blown onto the roof surface. Adequate areas must be available at the building perimeter for material and equipment staging. To accommodate regular inspection, a physical access method should be provided to the rooftop. Designated pathways across the green roof surface should be provided to prevent damage to plants and compaction of media during maintenance activities.

B.5.2.2 Consider Supplemental Irrigation during Plant Establishment

In the plant establishment phase, supplemental irrigation might be necessary to ensure plant survival and full roof coverage of roofing materials.

Appendix B.5 Green Roofs

B.5.2.3 Visitor Safety

Where public access is provided to the green roof for recreation or other purposes, consider barriers to mitigate fall risk. If vegetation includes grasses or other species that results in significant dead vegetation matter, incorporate fire prevention into maintenance plans or public signage.

B.5.3 Operations and Maintenance

Inspection and maintenance are critical to ensuring safe and effective functioning of green roofs. Table B-5-3 provides specific inspection and maintenance tasks.

Table B-5-3. Inspection and maintenance activities for green roofs

Task	Frequency	Indicator maintenance is needed	Maintenance notes
Media inspection	2 times/year	Internal erosion of media from runoff or wind scour, exposed underlayment components	Replace eroded media and vegetation. Adopt additional erosion prevention practices as appropriate.
Liner inspection	1 time/year	Liner is exposed or tenants have experienced leaks	Evaluate liner for cause of leaks. Repair or replace as necessary.
Outlet inspection	2 times/year	Accumulation of litter and debris around the roof drain or scupper or standing water in adjacent areas.	Litter, leaves, and debris should be removed to reduce the risk of outlet clogging. If sediment has accumulated in the gravel drain buffers, remove and replace the gravel.
Vegetation inspection	2 times/year	Dead plants or excessive open areas on green roof	Within the first year, 10% of plants can die. Survival rates increase with time.
Invasive vegetation	2 times/year	Presence of unwanted or undesirable species	Remove undesired vegetation. Evaluate green roof for signs of excessive water retention.
Temporary watering	1 time/2–3 days for first 1–2 months	Until established and during severe drought	Watering after the first year might be required.

B.5.4 References

East Baton Rouge Parish. 2007. *Stormwater*. Chapter 7. September 2007. Accessed January 7, 2013. <http://brgov.com/dept/planning/WWS/pdf/bmp7.pdf>.

New York City Department of Environmental Protection and New York City Department of Buildings. 2012. Guidelines for the Design and Construction of Stormwater Management Systems. July 2012. http://www.nyc.gov/html/dep/pdf/green_infrastructure/stormwater_guidelines_2012_final.pdf.

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B.6 Sand Filters



Surface sand filter at Remington Oaks, San Antonio, Texas. Source: Bender Wells Clark Design

B.6.1 Design

Sand filters have many of the same design elements as bioretention but are typically not planted. Table B-6-1 lists the steps involved in sand filter design.

Table B-6-1. Iterative design step process

Design step		Design component/ consideration	General specification
1	Determine BMP Size (B-91)	Use Appendix A	
2	Determine BMP Configuration (B-91)	Sand filter type	Based on available space and required access for maintenance, determine location and type of sand filter <ul style="list-style-type: none"> • Surface sand filters: installed in shallow depressions on surface. Require pretreatment by vegetated swales, filter strip, or forebay. • Subsurface sand filters: can be installed along the edges of roads and parking lots to conserve space. Must include a sedimentation chamber for pretreatment.
3	Determine BMP Function (B-93)	Impermeable liner	If non-infiltrating (per geotechnical investigation), use one of the following (as described in Common Design Elements): <ul style="list-style-type: none"> • Impermeable clay liner • Geomembrane liner • Concrete
		Lateral hydraulic restriction barrier	Use concrete or geomembrane to restrict lateral seepage to adjacent subgrades, foundations, or utilities.
		Underdrain	Schedule 40 PVC pipe with perforations (slots or holes) every 6 inches. 4-inch diameter lateral pipes should join a 6-inch collector pipe, which conveys drainage to the downstream storm network. Provide cleanout ports/observation wells for each underdrain pipe at spacing consistent with local regulations. See Common Design Elements .
		internal water storage (IWS)	If using underdrain and infiltration, elevate the outlet to create a sump for additional moisture retention to promote plant survival and treatment. Top of IWS should be more than 10 inches below the surface.
		No underdrain	If design is fully infiltrating, ensure that subgrade compaction is minimized.
4	Size the System (B-93)	Temporary ponding depth	No deeper than 8 feet (shallower depth should be used in residential areas or near schools and parks)
		Soil media depth	1.5–4 feet (deeper for better pollutant removal, hydrologic benefits, and deeper rooting depths)
5	Specify Soil Media (B-94)	Gradation	Washed concrete sand (ASTM C-33) free of fines, stones, and other debris
		Chemical composition	Total phosphorus < 15 ppm
		Gravel drainage layer	Separate sand media from underdrain with 2 inches of choking stone (ASTM No. 8) or geotextile over a 1.5-foot envelope of ASTM No. 57 stone

Design step		Design component/ consideration	General specification
6	Design Inlet and Pretreatment (B-95)	Inlet	Provide stabilized inlets (see Curb Cuts and Energy Dissipation)
		Pretreatment	Install rock armored forebay (concentrated flow), gravel fringe and vegetated filter strip (sheet flow), or vegetated swale
7	Select and Design Overflow/Bypass Method (B-96)	Outlet configuration	Online: All runoff is routed through system—install an elevated overflow structure or weir at the elevation of maximum ponding Offline: Only treated volume is diverted to system—install a diversion structure or allow bypass of high flows
8	Design for Multi-Use Benefits (B-96)	Include features to enhance aesthetics and public education.	

Step 1. Determine BMP Size

The sand filter must be sized to fully capture the desired or required design storm volume and filter it through the soil media. The sand filter should be oversized by 20 percent to accommodate the sediment accumulation in the surface of the sand filter, which reduces design volume (according to Barrett 2005). Relevant regulatory requirements are presented in detail in Chapter 2. Surface storage (in the ponding area) and soil pore space provide capacity for the design storm volume retention. Appendix A outlines methods for determining design runoff depths associated with a range of annual treatment efficiencies. Once the design runoff depth is determined (according to the desired level of treatment), a runoff volume can be determined for the contributing watershed using this depth and the methods outlined in Appendix A, *San Antonio Unified Development Code*, or *San Antonio River Basin Regional Modeling Standards for Hydrology and Hydraulic Modeling*.

Peak flow rates for the design storm should also be calculated, using the methods outlined in Appendix A so that the inlet and pretreatment can be accordingly sized and flow attenuation can be considered.

Step 2. Determine BMP Configuration

Sand filters require less space than many BMPs and are typically used in parking lots or other highly impervious areas. Two basic configurations are available for sand filters: surface sand filters with a vegetated filter strip as a pretreatment element, or subsurface sand filters with a sedimentation/grit chamber. The aboveground option requires more space to incorporate the pretreatment filter, and it provides more pathogen reduction from the surface's exposure to sunlight.

Surface: Surface sand filters require some method of pretreatment, such as a filter strip or swale, to remove large solids and reduce the velocity of stormwater entering the BMP. Surface sand filters can be integrated into the site plan as recreation facilities or open space as shown in Figure B-6-1. Access should always be provided for routine, intermittent, and rehabilitative maintenance activities.

Subsurface: Subsurface sand filters require very little space and are easily incorporated belowground into the edge of parking lots and roadways. Subsurface sand filters require a

Appendix B.6 Sand Filters

pretreatment sedimentation chamber (typically 1.5-feet-wide) to allow large solids to settle. An example of a subsurface sand filter with a sedimentation chamber is shown in Figure B-6-2.



Figure B-6-1. Surface sand filter at Parman Library, San Antonio, Texas. Source: Bender Wells Clark Design

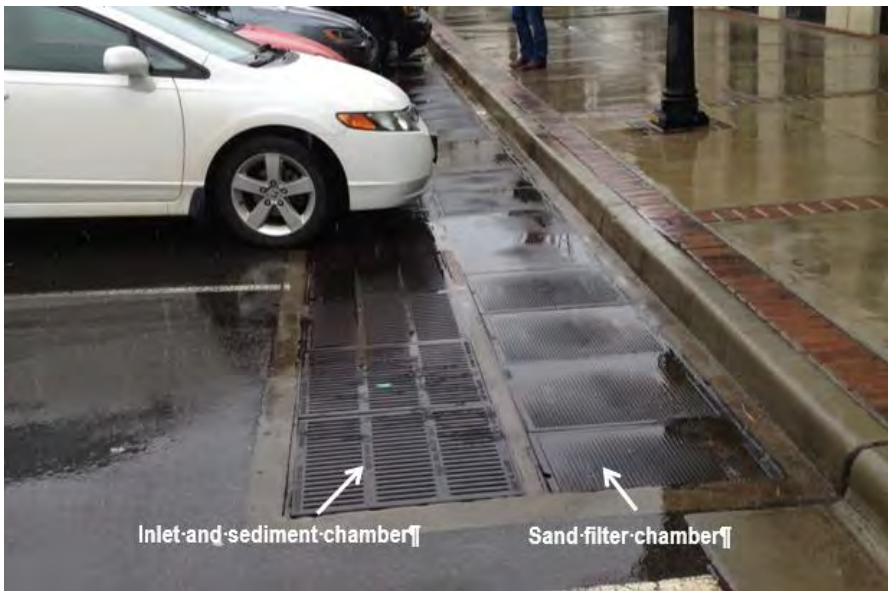


Figure B-6-2. Subsurface sand filter Raleigh, North Carolina. Source: Tetra Tech

Step 3. Determine BMP Function

Sand filters should be designed as infiltrating practices whenever practicable. Geotechnical testing and drainage requirements are the same as for [bioretention](#). Additionally, IWS can be used in infiltrating sand filters to increase residence time and improve volume reduction if subsoil infiltration rate is sufficiently high (e.g. infiltration rates of greater than 0.5 in/hr). Because plant survival is not a consideration in sand filters, the IWS elevation (underdrain outlet elevation) can be specified at 10 inches below the media surface. The IWS layer should not extend within 10 inches of the media surface because this is where the majority of sediment (and associated constituents) is captured; prolonged saturation of deposited sediments could cause previously captured pollutants to desorb/dissolve (Hunt et al. 2012). An example of a sand filter with IWS is shown in Figure B-6-3.

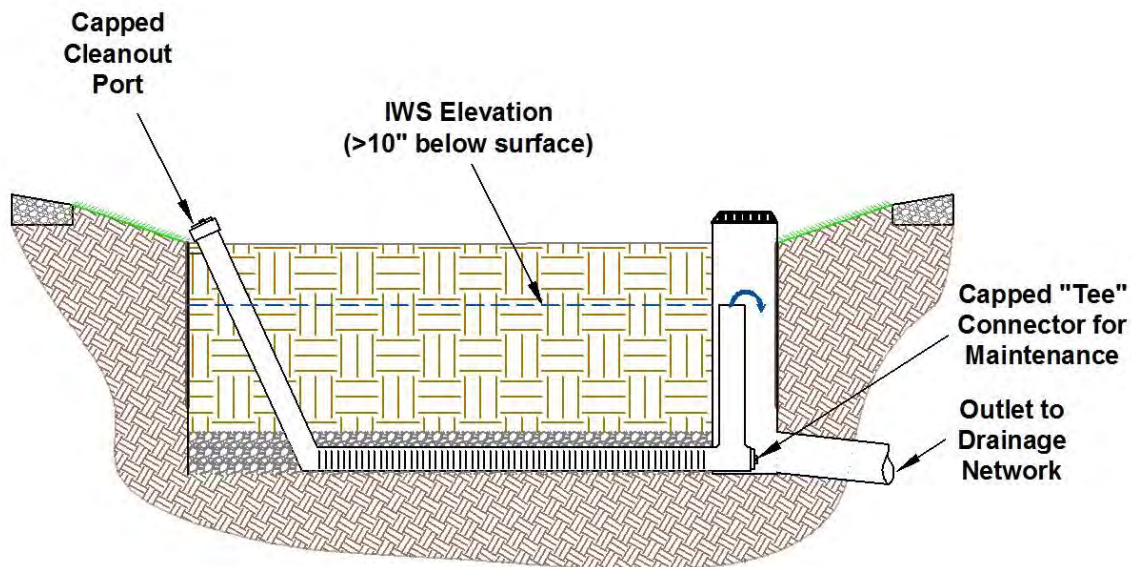


Figure B-6-3. Conceptual schematic of an infiltrating surface sand filter with IWS

Step 4. Size the System

Vertical components of sand filters are similar to bioretention, except that there are no constraints imposed by vegetation. The following subsections describe sand filter sizing.

Surface Ponding Depth

The ponding depth of sand filters is not limited as with some BMPs because the effect on vegetation is not a concern. Depth is determined by the ability of the sand filter to completely drain within 48 hours and, therefore, is a function of the surface area and infiltration rate of the sand media. Ponding depth should not exceed 8 feet as a safety precaution, and it should be shallower near residential areas, parks, and schools. When surface sand filters feature deep ponding depths, safety precautions consistent with conventional ponds (shallow water safety shelves, fencing, etc.) should be specified in the design.

Appendix B.6 Sand Filters

Media Depth

Sand media depth should be a minimum of 1.5 feet for sediment removal. For pollutant-specific media depths, see the [bioretention](#) section.

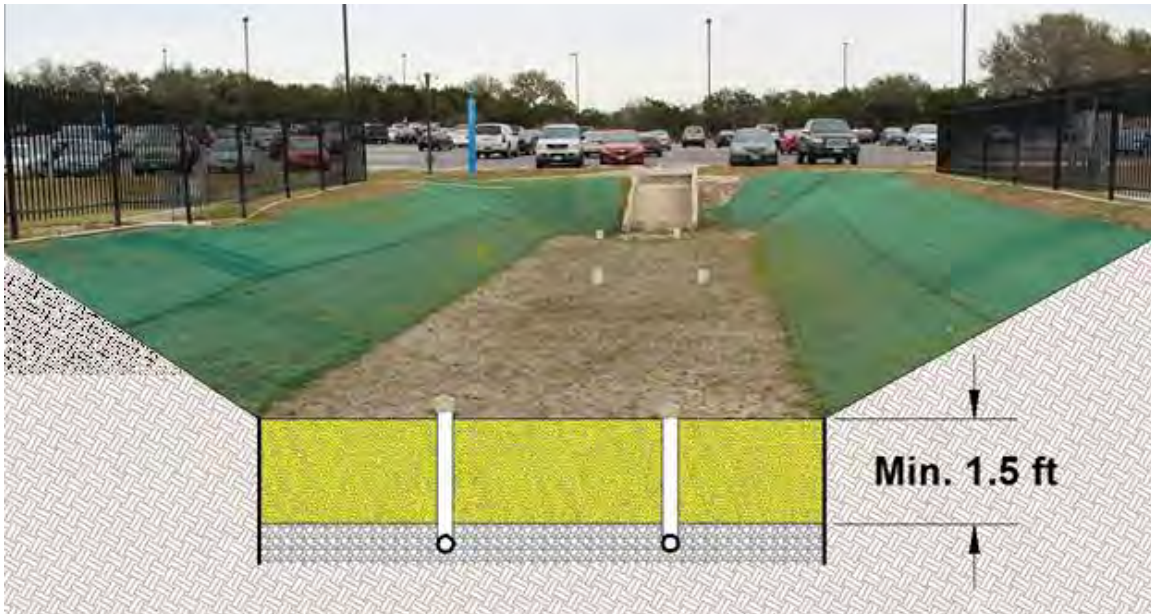


Figure B-6-4. Rendering showing sand filter geometry and profile, University of Texas at San Antonio, San Antonio, Texas. Source: Tetra Tech

Surface Area

The footprint of the sand filter should be sized using the equations provided in the [bioretention](#) section. Porosity of sand filter sand can be assumed equal to 0.4 for preliminary calculations, but actual laboratory-measured porosity should be used for final calculations. Although the footprint of sand filters can be smaller than bioretention because of deeper allowable surface ponding depths, smaller sand filters will require more frequent rehabilitative maintenance.

Step 5. Specify Soil Media

The soil media in the sand filter should be highly permeable; free of fines, stones, and other debris; and should meet the criteria listed in Table B-6-2. Media should be separated from gravel drainage layer using 2 inches of ASTM No. 8 choking stone or geotextile, as described in [Common Design Elements](#).

Table B-6-2. Sand filter soil media specifications

Parameter	Specification
Gradation	Media in the sand filter should consist of clean washed concrete sand (passing a one-quarter-inch sieve) per ASTM C-33.
Total phosphorus	High levels of phosphorus in the media have been identified as the main cause of BMPs exporting nutrients. All media should be analyzed for background levels of nutrients. Total phosphorus should not exceed 15 ppm.

Step 6. Design Inlet and Pretreatment

Erosive velocities and high sediment loads can be detrimental to sand filters. Both aboveground and belowground sand filters require some type of pretreatment before stormwater contacts the filter media. Aboveground sand filters should be constructed with a flow diversion, where possible, to divert volumes that exceed the water quality volume away from the sand filter to prevent excessive loads and erosive flow from affecting the filter media. Side slopes of above ground sand filters should be similar to a bioretention area. Below ground sand filters are typically installed in vaults and may be vertical. For more detail on diversion structures, see [Common Design Elements](#). Vegetated filters can also be used with aboveground sand filters where space is available. Flows entering sand filters should be diffused by passing over a level spreader before contacting the filter media to reduce flows, minimize filter media erosion, and distribute the flow over a larger surface area (see [Vegetated Filter Strips](#) for level spreader design details). Flows entering a subsurface sand filter should enter the sedimentation chamber and can be either concentrated or diffuse, depending on the inlet type. Concentrated flow, such as the flow for the end of a stormwater pipe, should enter the sedimentation chamber and flow into the media chamber over a level spreader to diffuse the flow before contacting the filter media as shown in Figure B-6-5. Diffuse flow passing into the sediment chamber over a level lip, such as the edge of a parking lot, should still flow over a level spreader before contacting the filter media. Figure B-6-5 shows a belowground sand filter with a diffuse flow inlet in a parking lot. It is important to distribute the flow across the surface area of the sand filter as much as possible to prevent the inflow from concentrating in one area, causing increased maintenance. The sedimentation chamber should be dewatered between storm events to prevent vector issues; this can be done by installing a perforated riser pipe surrounded by a gravel envelope in a trash rack (see [Common Design Elements](#)). Sedimentation chambers can vary in size depending on configuration, but should typically be designed to hold 50% of the design water quality volume and have a depth of 2 feet to 3 feet to minimize scour of sediment deposition (Knox County 2008; Claytor and Scheuler 1996). Detailed pretreatment sizing guidance can be found in Claytor and Schueler (1996).

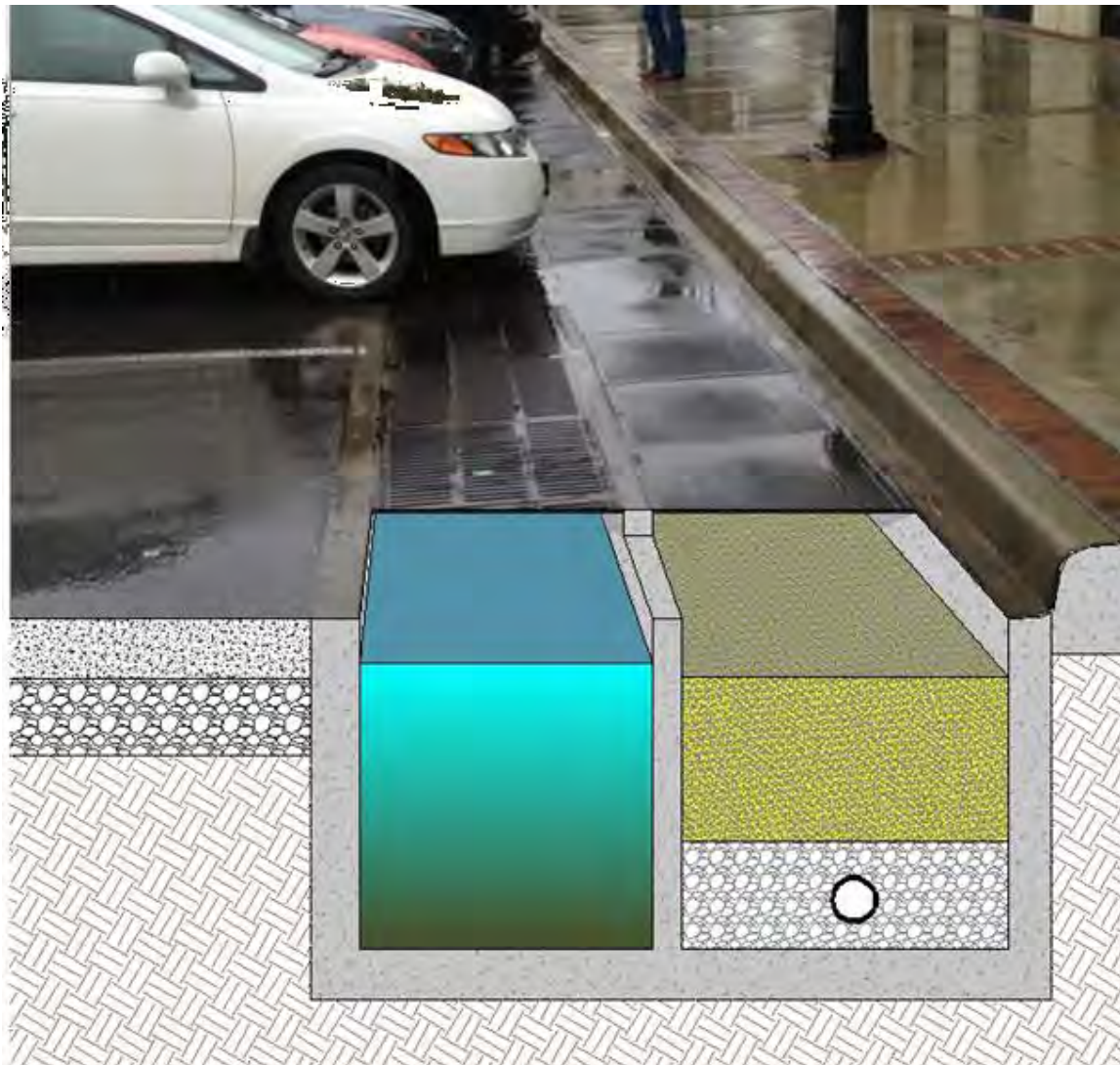


Figure B-6-5. Rendering showing subsurface sand filter with diffusive flow inlet and slot weirs between sedimentation chamber and sand filter chamber, Raleigh, North Carolina. Source: Tetra Tech

Step 7. Select and Design Overflow/Bypass Method

Sand filters can be designed as online or offline systems, but offline configurations are typically preferred to preserve the functional life of the filter media. Details for designing diversion structures for offline systems are provided in [Common Design Elements](#). An alternative overflow should be incorporated for all configurations as a contingency for when the filter media clogs; doing so will prevent damage to the BMP and surrounding areas. Overflow options are described in [Bioretention](#).

Step 8. Design for Multi-Use Benefits

Subsurface sand filters inherently provide multi-use benefits because they can be installed below areas dedicated for parking. Multi-use benefits should be provided for surface sand filters by including educational signage and kiosks.

B.6.1 Critical Construction Considerations

Construction considerations for sand filters are similar to those for [bioretention](#). For subsurface sand filters, care should be taken to verify elevations of all structures and allow for ease of access for maintenance.

B.6.2 Operations and Maintenance

Sand filters require regular, frequent maintenance of the media layer and pretreatment devices to ensure optimum infiltration, storage, and pollutant removal capabilities. Specific tasks are listed in Table B-6-3 and key activities are described below:

1. Erosion control: Inspect flow entrances, ponding area, and surface overflow areas periodically during the rainy season, and replace vegetation or erosion control materials if erosion has occurred (for a sand filter inspection and maintenance checklist, see Appendix F). Properly designed facilities with appropriate flow velocities will not have erosion problems except perhaps in extreme events. If erosion problems occur, the following must be reassessed: (1) flow velocities and gradients within the filter, and (2) flow dissipation and erosion protection strategies in the pretreatment area and flow entrance. If sediment other than the designed soil media is deposited in the media chamber, immediately determine the source in the contributing area, stabilize, and remove excess surface deposits.
2. Inlet: The inlet should be inspected after the first storm of the season, then monthly during the rainy season to check for sediment accumulation and erosion. Sediment can accumulate, especially at inlets where bypass structures are used, and should be inspected regularly. Any accumulated sediment that impedes flow into the sand filter should be removed and properly disposed of. Flow spreaders should be cleaned and reset as needed to maintain diffuse flows.
3. Overflow and underdrains: Sediment accumulation in the overflow device or underdrain system can cause prolonged ponding and potential flooding. Overflow and underdrain systems should be inspected after the first storm of the season, then monthly during the rainy season to remove sediment accumulation around the overflow. The underdrain system should be designed so that it can be flushed and cleaned as needed. If water is ponding over the filter media for more than 72 hours, the underdrain system should be flushed with clean water until proper infiltration is restored. Flow spreaders should be checked to maintain diffuse flow.
4. Sand media: If in question, have the soil analyzed for pollutant levels. A sediment depth indicator may be installed in the sedimentation chamber to indicate the depth of sediment accumulation as an indication that maintenance is required (according to Barrett 2005).
5. General maintenance: Trash and debris should be removed from the sand filter as needed. Any visual evidence of contamination from pollutants such as oil and grease should be removed as needed.

Appendix B.6 Sand Filters

Table B-6-3. Inspection and maintenance tasks for sand filters

Task	Frequency	Indicator maintenance is needed	Maintenance notes
Catchment inspection	Weekly or biweekly with routine property maintenance	Excessive sediment, trash, or debris accumulation on the surface of sand filter.	Permanently stabilize any exposed soil and remove any accumulated sediment. Adjacent pervious areas might need to be re-graded.
Inlet inspection	Once after first major rain of the season, then every 2 to 3 months depending on observed sediment and debris loads	Debris or sediment has blocked inlets	Remove any accumulated material.
Sedimentation chamber/forebay inspection	Every 2 months	Sediment has reached 6 inches deep (install a fixed vertical sediment depth marker) or litter and debris has clogged weirs between sedimentation chamber and sand filter chamber (for subsurface filters)	Remove accumulated material from sedimentation chamber. Remove and replace top 2 to 3 inches of sand filter if necessary.
Sand filter surface infiltration inspection	After major storm events or biannually	Surface ponding draws down in more than 48 hours	Remove and replace top 2 to 3 inches of sand filter, or as needed to restore infiltration capacity. Inspect watershed for sediment sources.
Outlet inspection	Once after first major rain of the season, then monthly	Erosion or sediment deposition at outlet	Check for erosion at the outlet and remove any accumulated sediment.
Miscellaneous upkeep	12 times/year		Tasks include trash collection, spot weeding, replacing soil media, and removing visual contamination.

B.6.3 References

- Barrett, M.E. 2005. *Complying with the Edwards Aquifer Rules. Technical Guidance on Best Management Practices*. RG-348. Prepared for Texas Commission on Environmental Quality, Field Operations Division, Austin, TX.
- Claytor, R.A., and T.R. Schueler. 1996. *Design of Stormwater Filtering Systems*. Center for Watershed Protection, Silver Spring, MD.
- Hunt, W.F., A.P. Davis, and R.G. Traver. 2012. Meeting hydrologic and water quality goals through targeted bioretention design. *Journal of Environmental Engineering* 138(6):698–707.
- Knox County. 2008. Knox County Tennessee Stormwater Management Manual. Volume 2 (Technical Guidance). [http://www.knoxcounty.org/stormwater/pdfs/vol2/3-1-8 Water Balance Calculations.pdf](http://www.knoxcounty.org/stormwater/pdfs/vol2/3-1-8%20Water%20Balance%20Calculations.pdf).

B.7 Stormwater Wetlands



Stormwater Wetland, Lenoir, North Carolina. Source: Tetra Tech

B.7.1 Design Steps

The design of a constructed stormwater wetland can be broken down to a nine-step process. Table B-7-1 summarizes the steps, which are described in greater detail.

Table B-7-1. Iterative design step process

Design step	Design component/ consideration	General specification
1 Determine BMP Treatment Volume and Flow Rates (B-101)	Use Appendix A. The design volume should be oversized by 20% to account for sediment accumulation over time.	
2 Perform Feasibility Water Balance (B-101)	Evapotranspiration, infiltration	Estimate rate of water loss during drought to ensure that water is maintained in deep pools (shallow water zones do not need to remain wet year round)
3 BMP Siting and Configuration (B-102)	BMP size	Incorporate into lowest areas of site
4 Determine Geotechnical Requirements and Specify Liner (B-103)	Geotechnical investigation and impermeable liners	See Common Design Elements
5 Design Inlet and Pretreatment (B-103)	Sediment forebay	Forebay should be 18–36 inches deep, 10% of the temporary ponding surface area, and should be lined with riprap for energy dissipation
6 Design Wetland Flow Path, Zones and Footprint (B-104)	Maximum flow path	The minimum length to width (L:W) ratio should be 2:1, but L:W should be maximized by creating a sinuous flow path and placing the outlet as far from the inlet as possible
	Wetland zones	<p>Deep Pools: 15%–20% of wetland surface area (including forebay), 18–36 inches deep</p> <p>Transition: 10%–15% of wetland surface area, transition between deep pool and shallow water, 12–18 inches deep, maximum slope of 1.5:1.</p> <p>Shallow Water: 40% of wetland surface area, 3–6 inches deep, flat or 6:1 slope (at least 6-foot radius around all deep pools to provide safety shelf). Shallow water depths (less than 6 inches) provide optimum conditions for plant survival and should be verified during construction inspection.</p> <p>Temporary Inundation: 30%–40% of wetland surface area, up to 12 inches deep, 3:1 slopes</p> <p>Detention Storage/Upland: Additional ponding depth can be provided for peak flow mitigation, as needed, but depth should generally not exceed 4 feet above the permanent pool elevation</p>

Design step	Design component/ consideration	General specification
7 Select and Design Outlet/Bypass Method (B-107)	Outlet configuration	Online: All runoff is routed through the wetland basin—install an elevated riser structure or weir with an orifice at the permanent pool elevation and an overflow at the maximum temporary ponding elevation (if additional peak flow mitigation is required, a second orifice can be placed at the temporary ponding elevation and the overflow can be elevated to detain the necessary runoff) Offline: Runoff in excess of the design water quality volume bypasses the wetland basin—design a diversion structure per the guidance in Common Design Elements
	Design drawdown orifice	Non-clogging orifices should feature a downturned pipe that extends 6 to 12 inches below the permanent pool elevation in an area of open water (deep pool) and allows drawdown of temporary ponding in 2 to 5 days
	Maintenance and emergency dewatering design	A protected inlet should be provided near the base of the outlet structure with a tamper-proof manual valve (intake should be sized one standard pipe size larger than needed to dewater the basin in 24 hours)
	Outfall pipe and emergency overflow	The outlet pipe should incorporate measures to prevent lateral seepage and should discharge to an adequately stabilized area; an emergency spillway should be provided to safely bypass extreme flood flows
8 Specify Soil Media (B-111)	Wetland vegetation substrate	At least 1 to 4 inches of low-phosphorus, organic topsoil over the impermeable layer is typically required for plant establishment
9 Select Vegetation (B-112)	Wetland vegetation by zone	See Plant List (Appendix E)
10 Design for Multi-Use Benefits (B-112)	Site specific	Include features to enhance habitat, aesthetics, recreation, and public education as desired.

Step 1. Determine BMP Treatment Volume and Flow Rates

The methods for determining wetland size are outlined in Appendix A. The wetland should be oversized by 20 percent to accommodate the sediment accumulation in the wetland, which reduces design volume (according to Barrett 2005).

Peak flow rates should also be calculated using methods outlined in the *San Antonio Unified Development Code* or *San Antonio River Basin Regional Modeling Standards for Hydrology and Hydraulic Modeling*, so that the inlet, pretreatment, outlet, bypass and other hydraulic features can be accordingly sized and flow attenuation considered.

Step 2. Perform Feasibility Water Balance

A stormwater wetland's function relies on the wetland retaining an adequate supply of water between storm events to ensure plant vigor and to maintain habitat for mosquito-eating fish (Hunt et al. 2005).

Appendix B.7 Stormwater Wetlands

Wetlands should have enough water supplied from groundwater, runoff, or baseflow so that the permanent pools will not draw down by more than 2 feet after a 30-day drought. Where seasonally low groundwater elevations intersect with the wetland features (see step 4) groundwater resources might be sufficient to supply enough water to ensure plant survival. In areas where an impermeable liner is incorporated into the wetland design, a water balance evaluation should be conducted to determine if the necessary water will be retained in the deep pools. In doing this, the designer should consider precipitation, evapotranspiration, runoff, infiltration (if unlined), and any other inputs or outputs of water from the system. Note that the water balance should be performed only for the deep pools because wetland plants established in shallow water zones are well-adapted to periods of drought. Guidance on one method for conducting a water balance is in Hunt et al. (2007) and Knox County (2008).

Step 3. BMP Siting and Configuration

Constructed stormwater wetlands are typically constructed in the lowest area of a site such that runoff can be conveyed by gravity flow and so that excavation is minimized. The stormwater wetland location should provide adequate elevation difference, typically 3 feet or more, to discharge water to the existing stormwater network without the need for pumps. Constructed wetlands can be incorporated along the perimeter of a site by designing a long, linear footprint, or it can serve as an attractive amenity in common areas of developments. If the entire design volume cannot be stored in one location or if utility conflicts are apparent, wetland pockets can be distributed between several locations and connected with vegetated channels or buried conduit. For an example wetland configurations, see Figure B-7-1.

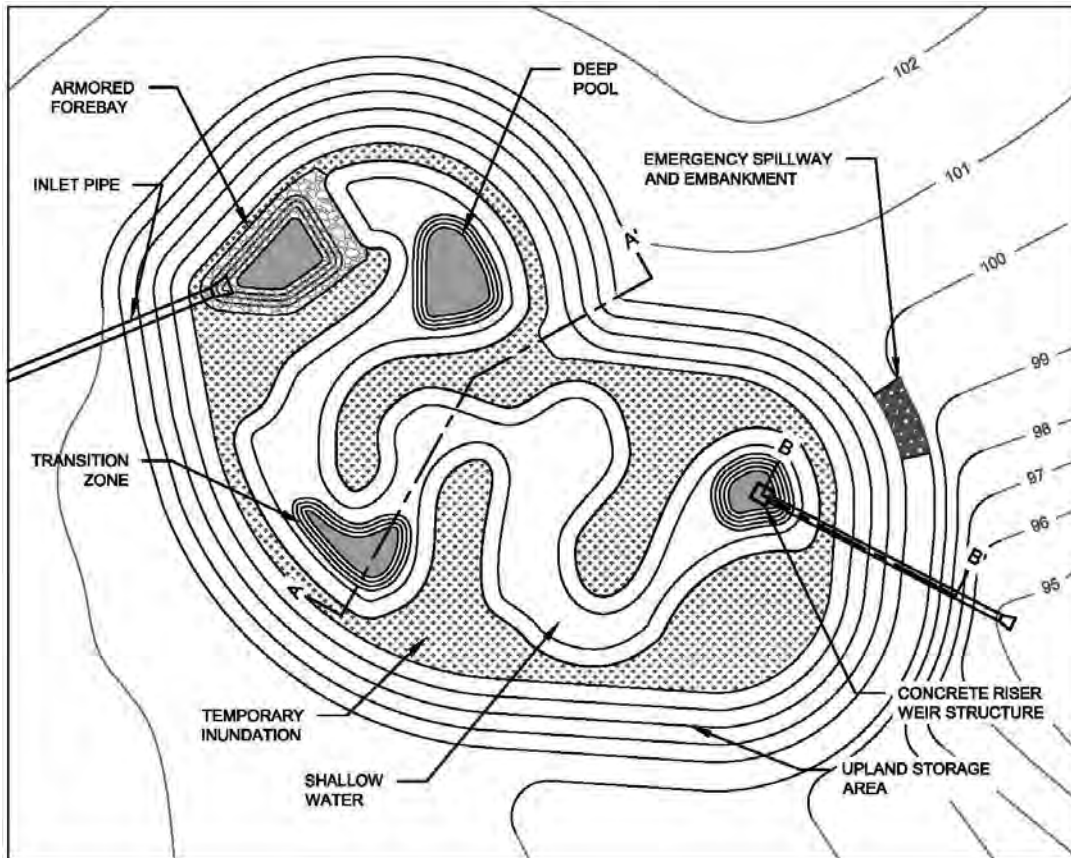


Figure B-7-1. Example wetland configuration

Step 4. Determine Geotechnical Requirements and Specify Liner

Unlike many other stormwater BMPs, stormwater wetlands are *not* intended to infiltrate runoff. As such, the subsoil conditions must be investigated to determine in situ infiltration rates, depth to seasonal high groundwater table, and underlying geology (including proximity to Edwards Aquifer Recharge, Contributing, and Transition zones). For details regarding geotechnical investigations, see [Common Design Elements](#).

If the site features a high groundwater table and is in an area where infiltration is permitted, hydraulic restriction layers might not be needed—in these situations the high groundwater table will help maintain a permanent pool in the stormwater wetland. If the groundwater table is deeper than the proposed permanent pool elevation or the site is in an area with sensitive subsurface resources, adequate hydraulic restriction layers should be specified to prevent infiltration. For details on designing hydraulic restriction barriers, see [Common Design Elements](#).

Step 5. Design Inlet and Pretreatment

A rock-lined forebay stills incoming runoff and allows larger particles to settle. Forebays should conform to the design recommendations provided in 7-2 and illustrated in Figure B-7-2.



Figure B-7-2. Rock-lined forebay visible in a newly planted stormwater wetland, Wilmington, North Carolina. Source: Tetra Tech

Table B-7-2. Recommended specifications for stormwater wetland forebay design

Component	Specification
Area	10% of wetland surface area
Depth	3–5 feet deep near inlet, then sloping up to 2–3 feet deep toward berm (incline dissipates energy and promotes particle settling); deeper depths can be provided for sediment storage
Berm/Weir Elevation	A berm or weir should contain inflow up to the elevation of temporary ponding and provide for safe and diffuse overflow into main body of the wetland (overflow should <i>not</i> occur near side slopes and embankments)
Materials	The entire forebay should be lined with appropriately sized riprap (Class B is typically sufficient) or concrete (concrete provides for easy maintenance with vacuum truck) such that aggregate will not be transported under high flows.

Step 6. Design Wetland Flow Path, Zones and Footprint

Designing the internal wetland features, zones, and footprint is an iterative process. The design must balance storage volume requirements with existing site grading and desired flow length ratios.

The flow length through the wetland should be maximized to improve residence time and treatment. This can be done by incorporating a sinuous flow path or by using berms to form *racetrack* style configurations (see Figure B-7-3 and Figure B-7-4). The L:W ratio (as measured from inlet to outlet and using the average width of the basin) should be 2:1, minimum, but 3:1 is preferred. The width of the flow path will be determined by the flow length and the desired shallow water area.



Figure B-7-3. A sinuous pattern increases the flow path in a stormwater wetland, Wilmington, North Carolina. Source: Tetra Tech



Figure B-7-4. An earthen berm elongates the flow path in a racetrack-style stormwater wetland where the inlet and outlet are located in close proximity, Lenoir, North Carolina. Source: Tetra Tech

Appendix B.7 Stormwater Wetlands

The wetland area should be divided into four zones, as specified in Table B-7-3 and Figure B-7-5. Although deep pools are important for maintenance of water and wildlife (including mosquito-eating predators) during dry periods, the shallow water zone is also critical for plant survival. One of the most common causes of wetland plant die-off is designing the shallow water zone *too* deep—depths greater than 6 inches will reduce plant survival rates and encourage the encroachment of invasive plant monocultures which can, in turn, harbor mosquito habitat. (Hunt et al. 2005).

Table B-7-3. Wetland zones

Deep Pools: 15%–20% of wetland surface area (including forebay), 18–36 inches deep
Transition: 10%–15% of wetland surface area, transition between deep pool and shallow water, 12–18 inches deep, maximum slope of 1.5:1.
Shallow Water: 40% of wetland surface area, 3–6 inches deep, flat or 6:1 slope (at least 6-foot radius around all deep pools to provide safety shelf). Shallow water depths (less than 6 inches) provide optimum conditions for plant survival and should be verified during construction inspection.
Temporary Inundation: 30%–40% of wetland surface area, up to 12 inches deep, 3:1 slopes
Detention Storage/Upland: Additional ponding depth can be provided for peak flow mitigation, as needed, but depth should generally not exceed 4 feet above the permanent pool elevation

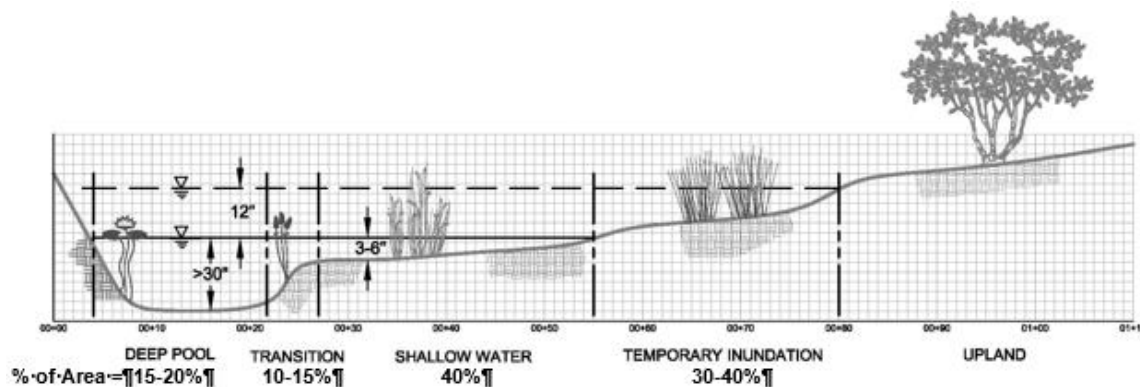


Figure B-7-5. Wetland zones

The wetland footprint must be configured so that the wetland contains in its temporary and permanently ponded areas a storage volume equal to or greater than the treatment volume detailed in step 1. Determine the storage volume by using algorithms available in computer aided design software, which is typically used to develop the wetland grading plan. Alternatively, use the equation below to evaluate the storage volume for a proposed wetland configuration.

$$V = (2DP) + (0.375SW) + (1.25TZ) + [TP(DP + SW + TZ)] + \left[TI \left(\frac{1}{2TP} \right) \right] \quad \text{[Equation B-7-1]}$$

where:

V = treatment volume contained in the stormwater wetland

DP = area of wetland dedicated to deep pool zone (sq ft)

SW = area of wetland dedicated to shallow water zone (sq ft)

TZ = area of wetland dedicated to transition zone (sq ft)

TP = temporary ponding depth of wetland (ft)

TI = area of wetland dedicated to temporary inundation zone

Step 7. Select and Design Outlet/Bypass Method

As with other BMPs, stormwater wetlands can be designed as online or offline systems. Regardless of the configuration, mechanisms are required to draw down water in the wetland basin between storm events and for maintenance. The following sections discuss the outlet design.

Online versus Offline Configuration

The outlet or bypass configuration will depend on the drainage area size, available space for onsite detention, and design goals. If a wetland is designed as an offline system, a diversion structure should be installed to route the design volume into the basin (according to the guidance provided in [Common Design Elements](#)). Offline wetlands can be smaller than online wetlands, which makes them ideal for retrofit scenarios because they need not provide capacity (volumetrically and hydraulically) for routing higher flows.

If an online system is desired, all runoff from the catchment is routed through the basin and out a multistage outlet structure with capacity to allow high-volume flows to safely overflow. The outlet structure should be placed near the edge of the wetland for easy maintenance access. If additional peak flow mitigation is desired, a secondary orifice or weir can be installed at the elevation of temporary ponding and the overflow can be elevated to allow larger storms to bypass. The maximum detention depth should be 4 feet above the permanent pool to reduce effects on wetland vegetation. Example outlet structures are shown in Figure B-7-6.

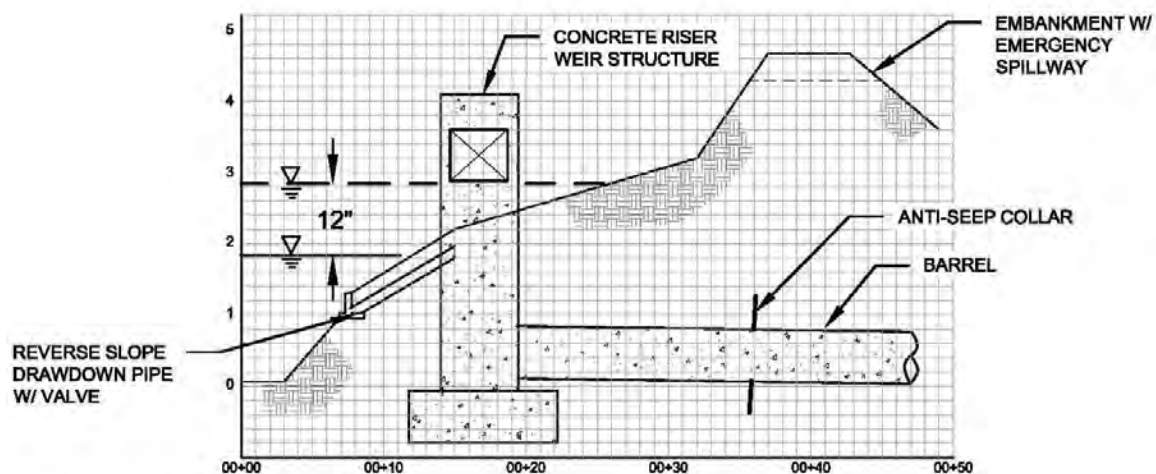


Figure B-7-6. Wetland outlet structure schematic

Appendix B.7 Stormwater Wetlands

Design drawdown Orifice

A non-clogging orifice should be designed to draw down the water quality design volume in 2 to 5 days. Longer residence times are preferred to maximize treatment efficiency. The orifice should be equipped with a trash rack or a downturned intake pipe that extends 6 to 12 inches below the surface of a nearby area of open water, as shown in Figure B-7-7. Submerging the intake pipe will reduce the risk of blockage caused by floating debris. A capped tee-connection can be installed on the end of the pipe for easy cleaning (when the cap is removed, a ramrod can be used to dislodge any debris that has accumulated around the submerged intake). Additional guidance on trash racks and non-clogging orifices is provided in [Common Design Elements](#) and Barrett (2005).

Additionally, installing an adjustable orifice can help with plant establishment (an example shown in Figure B-7-8 uses an orifice in a metal plate that can be rotated on a flange fitting to adjust orifice elevation); lowering the orifice to maintain shallower permanent pool depths for several weeks after planting will improve plant survival rates. After plants are established, the adjustable orifice can be elevated to capture the intended water quality design volume. Alternatively, the outlet structure can include a flashboard riser that uses removable boards to control the stage of water in the wetland (Figure B-7-9).



Figure B-7-7. A downturned inlet pipe with an orifice extends into a deep pool in a small stormwater wetland, Raleigh, North Carolina. Source: Tetra Tech

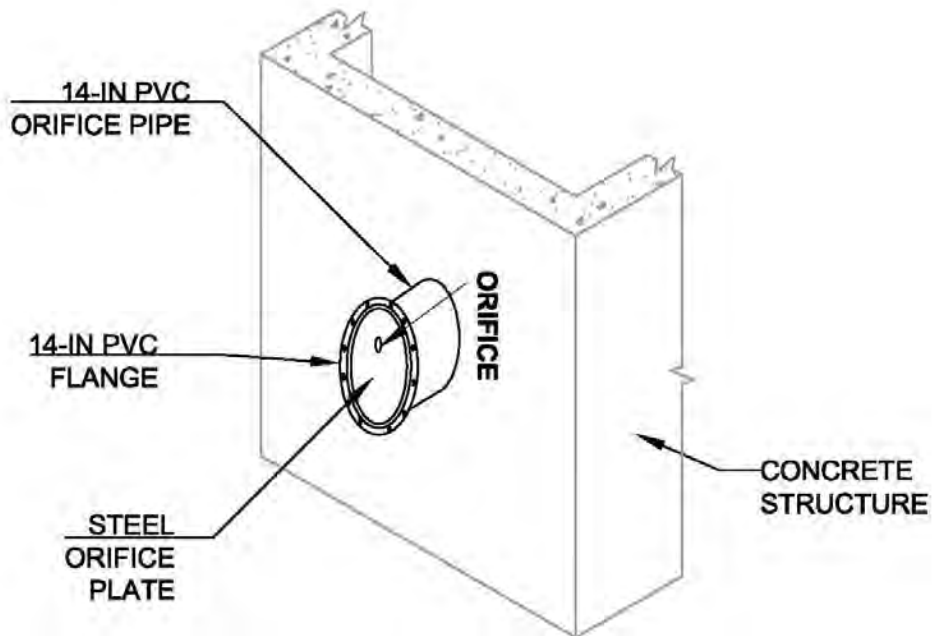


Figure B-7-8. Example schematic of an adjustable orifice plate



Figure B-7-9. A flashboard riser allows adjustment of water level during plant establishment and for maintenance, Wilmington, North Carolina. Source: Tetra Tech

Appendix B.7 Stormwater Wetlands

The drawdown orifice should be sized to draw down the temporary ponding depth using the following orifice equation:

$$Q = C_d \pi \left(\frac{d^2}{48} \right) \sqrt{2gH} \quad \text{[Equation B-7-2]}$$

where:

Q = Discharge (cfs) computed by dividing the storage volume above the permanent pool by the desired drawdown period

C_d = Coefficient of Discharge (0.60 for sharp edged orifice without projections)

π = pi (3.14)

d = orifice diameter (in)

g = acceleration of gravity (32.2 ft/sec²)

H = driving head (ft) measured from the *center* of the drawdown orifice to water surface.

Note: Use $H = \frac{H_0}{3}$ as an approximation of the driving head throughout the drawdown period.

where:

H_0 = Driving head (ft) measured from the center of the drawdown orifice to the crest of the overflow/bypass weir.

Design Maintenance/Emergency Dewatering Intake

A manually operated intake valve should be provided at the lowest possible stage of the wetland to allow drawdown for maintenance. The intake should be protected with gravel or a trash rack, or both, to minimize clogging and be sized one standard pipe size larger than would be needed to dewater the entire wetland basin within 24 hours. The valve should have locking features to prevent unauthorized dewatering. Figure B-7-10 shows an example of a maintenance dewatering intake. A flashboard riser can also be installed for rapid dewatering (as discussed in the previous subsection).



Figure B-7-10. Maintenance dewatering intake design that could be used in a stormwater wetland, Raleigh, North Carolina. Source: Tetra Tech

Outfall Pipe and Emergency Spillway

The outfall should be adequately stabilized with energy-dissipation devices to prevent scour of downstream sediment (for energy dissipation configurations, see [Common Design Elements](#)). A pipe collar or other engineering solution should also be installed to prevent seepage of water through the soil along the edge of the pipe. This *pipng* can cause dangerous failure of embankments and drain the wetland’s permanent pool. Additionally, an emergency spillway should be provided to allow 1 foot of freeboard during the 25-year event and should safely convey flows up to and including the 1percent average recurrence interval event (Barrett 2005).

Step 8. Specify Soil Media

A 1- to 4-inch layer of topsoil must be provided for plant establishment because stormwater wetlands are typically lined with hydraulic restriction layers. Depth of soil will depend on specified plantings and underlying soil characteristics—consult a plant specialist as needed. Native soils excavated in construction can be used, but a soil test should confirm that the soils contain adequate nutrients for plant survivability (subsoils tend to be relatively *infertile*, so topsoil should be separately stockpiled for this purpose). Soils should not contain excessive levels of phosphorus (greater than 15 ppm) because this nutrient tends to dissociate from the soil under saturated conditions.

Step 9. Select Vegetation

Although wetlands are typically wet, most native wetland plants are well adapted to surviving long periods of drought. Emergent plant survival rates dramatically decrease when normal water depth exceeds 6 inches. It is recommended that a diverse selection of native flowering, emergent species are planted throughout the shallow water zone (3 to 6 inch depth) around the wetland. This will provide the optimum habitat for mosquito predators, such as dragonflies, and reduce plant die-off. At least three species, preferably more, should be planted in each wetland zone (see Figure B-7-5).

Although trees and shrubs can provide habitat, shade, and aesthetic benefits, take care to immediately remove woody vegetation from embankments to prevent geotechnical failures. A full plant list is in Appendix E.

Step 10. Design for Multi-Use Benefits

Stormwater wetlands can provide excellent ecosystem services and aesthetic value to stakeholders. In addition to enhancing biodiversity and beautifying the urban environment with native vegetation, the following components can be incorporated into stormwater wetlands to promote multi-use benefits:

- Simple signage or information kiosks can educate the public on the benefits of watershed protection measures or provide a guide for native plant and wildlife identification.
- Boardwalks, wildlife viewing platforms, and benches can be provide to encourage interaction.
- Volunteer groups can be organized to perform basic maintenance as an opportunity to raise public awareness.
- Wetlands can be used as outdoor classrooms for school science projects and field trips.

B.7.2 Critical Construction Considerations

B.7.2.1 Provide Maintenance Access

To maintain stormwater wetlands, maintenance crews and equipment must occasionally access wetland components. Wetland design should incorporate a dedicated access easement from a public road to the wetland and an appropriate maintenance staging area. The grading plan for the wetland should incorporate access paths as appropriate for maintenance equipment to reach critical maintenance points including, for example, the forebay and outlet. The site geotechnical analysis will determine whether the access path must be stabilized to support heavy equipment.

B.7.2.2 Incorporate Nuisance Wildlife Deterrents

Improperly maintained stormwater treatment wetlands provide ideal habitat for urban waterfowl and other nuisance wildlife. Some species such as snakes might be perceived as distasteful to nearby citizens but do not negatively affect the function of the wetland itself. Other species such as geese and nutria might negatively affect the wetland including grazing wetland plants, disturbing bottom sediments, and contributing pollutants through fecal matter. Burrowing animals may also compromise the geotechnical stability of embankments. Various methods can be used to deter or remove nuisance species from the wetland. Each method should be considered in the context of project objectives, local laws, and stakeholder perception of the nuisance. The most effective method control of nuisance waterfowl is to maintain tall vegetation around the entire perimeter of the wetland because waterfowl tend to be wary of tall vegetation for fear of hidden predators. Abundant, diverse vegetation can also provide favorable habitat for dragonflies and other mosquito

predators, whereas monocultures of vegetation (such as *Typha. spp.* or *Phragmites spp.*) can harbor mosquito larvae in dense mats of roots and detritus (Hunt et al. 2005). Where advanced vector control is required, Barrett (2005) recommends introducing *Gambusia affinis* (mosquito fish) at a density of 200 fish per acre of permanent pool. Several references are available for appropriate methods of nuisance wildlife control:

- *Managing Waterfowl in Stormwater Ponds:*
<https://www.clemson.edu/extension/water/stormwater-ponds/problem-solving/nuisance-wildlife/waterfowl/index.html>
- *Goose Control Best Management Practices to Prevent Pollution of Ponds, Streams, and Rivers:* http://www.pittsfieldtp.org/NRC_Goose_Control
- *Nuisance Wildlife Repellent Handbook:*
http://files.dnr.state.mn.us/assistance/backyard/livingwith_wildlife/repellent_handbook.pdf

B.7.3 Operation and Maintenance

Inspection and maintenance area key to ensure the proper function and aesthetics of stormwater wetlands. Table B-7-4 lists specific operation and maintenance tasks.

Table B-7-4. Inspection and maintenance tasks for stormwater wetlands

Task	Frequency	Indicator maintenance is needed	Maintenance notes
Forebay inspection	Weekly or biweekly	Internal erosion or excessive sediment, trash, or debris accumulation	Check for sediment accumulation to ensure that forebay capacity is as designed. Remove any accumulated sediment.
Basin inspection	1 time/year	Excessive sediment, trash, and/or debris accumulation in the wetland	Remove any accumulated sediment. Adjacent pervious areas might need to be re-graded.
Outlet inspection	Weekly or biweekly with routine property maintenance	Accumulation of litter and debris in wetland area, large debris around outlet, internal erosion	Remove litter, leaves, and debris to reduce the risk of outlet clogging and to improve facility aesthetics. Erosion should be repaired and stabilized.
Mowing	2–12 times/year	Overgrown vegetation on embankment or adjacent areas	Frequency depends on location and desired aesthetic appeal.
Embankment inspection	1 time/year	Erosion at embankment	Repair eroded areas and revegetate.
Remove and replace dead vegetation	1 time/year	Dead plants or excessive open areas in wetland	Within the first year, 10% of plants can die. Survival rates increase with time.
Temporary watering	1 time/2–3 days for first 1–2 months	Until establishment and in severe drought	Watering after the initial year might be required.
Nuisance wildlife management	Biweekly or as needed	Animals, feces, or burrows evident in or around wetland.	Maintain diverse vegetated shelf around entire basin. Eliminate monocultures and replace with diverse, vegetation. Employ qualified wildlife management professionals if needed.
Fertilization	1 time initially	Upon planting	One-time spot fertilization for first year vegetation if needed.

B.7.4 References

- Barrett, M.E. 2005. *Complying with the Edwards Aquifer Rules. Technical Guidance on Best Management Practices*. RG-348. Prepared for Texas Commission on Environmental Quality, Field Operations Division, Austin, TX.
- Hunt, W.F., C.S. Apperson, and W.G. Lord. 2005. Mosquito Control for Stormwater Facilities. *Urban Waterways*.
<http://www.bae.ncsu.edu/stormwater/PublicationFiles/Mosquitoes2005.pdf>
- Hunt, W., M. Burchell, J. Wright and K. Bass. 2007. Stormwater Wetland Design Update: Zones, Vegetation, Soil and Outlet Guidance. *Urban Waterways*. North Carolina State Cooperative Extension Service, Raleigh, NC.
<http://www.bae.ncsu.edu/stormwater/PublicationFiles/WetlandDesignUpdate2007.pdf>
- Knox County. 2008. 3.1.8 Water Balance Method. Knox County Tennessee Stormwater Management Manual. Volume 2 (Technical Guidance).
[http://www.knoxcounty.org/stormwater/pdfs/vol2/3-1-8 Water Balance Calculations.pdf](http://www.knoxcounty.org/stormwater/pdfs/vol2/3-1-8%20Water%20Balance%20Calculations.pdf).

B.8 Extended Detention Basins



Extended Detention Basin in Grant Ranch, Colorado. Source: Urban Drainage Flood Control District

B.8.1 Design Steps

The design of an extended detention basin can be broken down into the following process summarized in Table B-8-1 and described in greater detail below the table.

Table B-8-1. Iterative design step process

Design Step		Design component/ consideration	General Specification
1	Determine BMP Treatment Volume (B-119)	The design volume should be oversized by 20% to account for sediment accumulation over time.	
2	Determine Flood Control Volume (B-119)	Based on the appropriate local requirements*	
3	BMP Siting and Configuration (B-119)	BMP location	Locate down gradient of disturbed/developed areas, in an area that will collect the most runoff from the site's impervious surfaces; avoid steep slopes; limit tree removal, which will de-stabilize soils and may contribute pollutants to influent.
		BMP size and shape	To maximize sedimentation processes, the basin length (measured along flow path from inlet to outlet) to width ratio should be between 2:1 and 3:1. Side slopes should be no steeper than 3:1 and should be 4:1 or flatter for improved safety, maintenance, and aesthetics.
4	Determine Geotechnical Requirements and Specify Liner if Necessary (B-120)	Geotechnical investigation and impermeable liners	Consider location and potential benefit and concerns of infiltration. See Common Design Elements
5	Design Inlet and Pretreatment (B-122)	Sediment forebay	The forebay volume should be sized to 10% of water quality volume and be 2 to 5 feet deep. It should incorporate a sediment depth marker, for measuring accumulation of sediment, as well as energy dissipation at the inlet in order prevent erosion or resuspension of sediment.
		Other forms of pretreatment	Vegetative Filters and Grassy swales can be incorporated upstream or downstream of EDB. See Vegetated Swales .
6	Design Basin Flow Path and Zones (B-123)	Maximum flow path	The minimum length to width (L:W) ratio must be at least 2:1, but L:W should be maximized by creating a sinuous flow path and placing the outlet as far from the inlet as possible. Baffles may also be considered.

Appendix B.8 Extended Detention Basins

Design Step		Design component/ consideration	General Specification
		Basin zones	<p>Trickle or Low Flow Channel: To convey flow from the forebay to the micropool, a concrete lined low flow channel or trickle channel is required; a slope between 0.4% - 1% and 9 inches deep is recommended; channel can be “V” shaped or a concrete channel with curbs</p> <p>Micropool: 10% of treatment volume or 5% of the surface area of the water quality pool; the micropool should be a permanent pool located near the outfall; slopes should be 3:1 with a minimum surface area of 10 square feet; micropools should not have a low flow pilot channel</p> <p>Detention Storage: Additional ponding depth can be provided for peak flow mitigation; the design storage volume should be based on the appropriate local requirements</p>
7	Select and Design Outlet/Bypass Method (B-125)	Outlet configuration	The outlet should be designed as a riser with orifices to discharge the water quality volume over a 48 hour period. The basin must include the low-flow outlet to slowly release water, additional outlets to release peak flows of larger design storms, and trash rack to prevent clogging of both outlets. See local ordinances for flood discharge requirements.
		Design drawdown orifice	Non-clogging orifices sized to allow for complete drawdown of the water quality volume in 48 hours and no more than 50% of the water quality volume should drain from the facility within the first 24 hours. The lowest orifice is to be placed at the design elevation for the micropool.
		Maintenance	A protected inlet should be provided near the base of the outlet structure with a tamper-proof manual valve (intake should be sized one standard pipe size larger than needed to dewater the basin in 24 hours).
		Outfall pipe and emergency overflow	The hydraulic design of the outfall structure should consider tailwater effects from downstream waterways; an emergency spillway should be sized to safely pass the flow based on the appropriate local requirements for the flood control detention volume.
		Trash rack	Trash racks should be designed so as to prevent clogging of the smallest outlet opening. This may require design of a grate or screen for the water quality orifices in addition to a larger rack for the flood control openings. Trash racks must be large enough so that partial clogging will not adversely restrict flows reaching the control outlet. Spacing of the rack bars should be wide enough to avoid interference, but close enough to provide the level of clogging and safety protection required.

Design Step		Design component/ consideration	General Specification
8	Select Vegetation (B-132)	Vegetation by zone	Basin bottom, berms, and side slopes should be planted with native or meadow grasses. See Appendix E - Plant List. A minimum 25-foot vegetative buffer should extend away from the top of the pond slope in all directions – woody vegetation should not be planted in this zone, but existing trees should remain.
9	Design for Multi-Use Benefits (B-132)	Site specific	Include features to enhance habitat for beneficial pollinators, aesthetics, recreation, and public education as desired.

*Detention requirements based on local ordinances for design flood events and freeboard requirements. Refer to Section G-2 in Appendix G for local ordinances in the San Antonio River Basin.

Step 1. Determine BMP Treatment Volume

The extended detention basin should be sized to fully capture the desired or required design storm volume. Consult with the appropriate entities for the required regulatory guidance on a design storm. Once the design storm is known, Equation 1 from Appendix A can be used to calculate the water quality volume.

The forebay and primary basin should be oversized by 20 percent to accommodate sediment accumulation, which reduces design volume (Barrett, 2005). Peak flow rates for the design storm should also be calculated so that the inlet and outlets may be appropriately sized and flow attenuation designed.

Step 2. Determine Flood Control Volume

Total volume should be estimated based on the storm of interest. Peak flow rates should be calculated using methods outlined in local ordinances, such as the *San Antonio Unified Development Code* or *San Antonio River Basin Regional Modeling Standards for Hydrology and Hydraulic Modeling*, so that the inlet, pretreatment, outlet, bypass and other hydraulic features can be accordingly sized and flow attenuation considered.

Step 3. BMP Siting and Configuration

To identify the appropriate location of EDBs, the designer should consider flow patterns and try to place in the lowest area of a site such that runoff can be conveyed naturally by gravity flow and to minimize excavation. Locating the EDB near steep slopes should be avoided. It is recommended to locate the basin where tree removal can be limited to prevent destabilization of soil and potential increase in sediment loads.

For an example EDB configuration, see Figure B-8-1. The basin length to width ratio, which is measured along flow path from inlet to outlet, should optimally be between 2:1 and 3:1 to maximize sedimentation processes. Side slopes should be no steeper than 3:1 and should be 4:1 or flatter for improved safety, maintenance, and aesthetics.

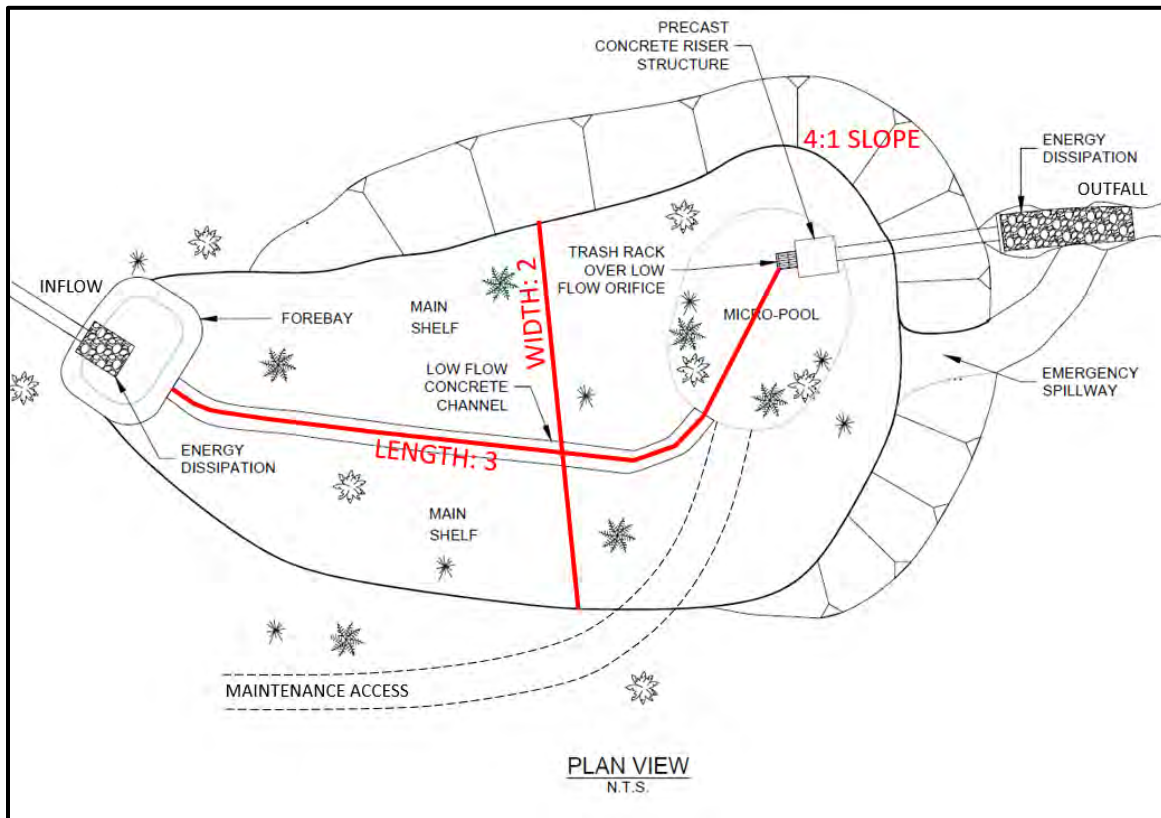


Figure B-8-1. Example 3- Extended Detention Basin Configuration

Step 4. Determine Geotechnical Requirements and Specify Liner if Necessary

The primary pollutant removal pathway for EDBs is not infiltration of runoff. However, in areas where soils are appropriate and groundwater water quality hot spots are not present, infiltration can be an effective method to treat pollutants. The subsoil conditions must be investigated to determine in situ infiltration rates, soil composition, depth to seasonal high groundwater table, and underlying geology (including proximity to bedrock or Edwards Aquifer Recharge, Contributing, and Transition zones). For details regarding geotechnical investigations, see [Common Design Elements](#). If clay, bedrock, or other impermeable layers are present in the subsoil, then infiltration should not be anticipated in the EDB design.

The lowest elevation in the EDB should be at least 2 feet above the high groundwater table and one foot above bedrock. Adequate clearance from the water table is essential in order to keep the basin bottom maintainable and dry. Permanently wet bottoms can become breeding grounds for mosquitos. If there is a risk for contamination of groundwater below the facility or if the site is in an area with sensitive subsurface resources, adequate hydraulic restriction layers should be specified to prevent infiltration. For details on designing hydraulic restriction barriers, see [Common Design Elements](#).

EXAMPLE STEP 4: DETERMINE THE MAXIMUM DEPTH OF THE EDB

The location selected for the EDB has the following geotechnical characteristics:

Depth to Seasonally High Water Table = 20 feet
Depth to Bedrock = 100 feet
Depth to Clay = 10 feet

An EDB with a designed bottom depth 15 feet below the existing ground surface would have:

- 5 feet water table clearance (20 ft – 15 ft)
- 85 feet bedrock clearance (100 ft – 15 ft)
- Interference with the clay layer at bottom 5 feet (10 ft – 15 ft)

Conclusion: The basin will be dry between rain events with no groundwater interference. Bedrock will not restrict infiltration or construction activity. Presence of a clay layer will likely prevent water from infiltrating.

Note: A depth of 15 feet is only suitable if there is adequate surface area available.

Use a trial and error approach to determine the surface area required to hold 177,600 cubic feet (calculated in Step 2) in a total depth of 15 feet. This is because the volume of the basin will depend on the bottom shape and side slopes of the basin.

To estimate the volume of a proposed basin using the end-area method:

Divide the basin into stages by drawing contours no more than 5 vertical feet apart. Determine the area under each contour. Next determine the volume of each stage using the following formula:

$$V = \frac{1}{2} H (A_1 + A_2)$$

Where:

V = Volume of each slice

A₁ = the area of the contour at the bottom of the stage

A₂ = the area of the contour at the top of the stage

H = the vertical distance between A₁ and A₂.

Finally, sum the volume of each stage to find the total volume of the proposed basin.

Step 5. Design Inlet and Pretreatment

A rock-lined forebay reduces the velocity of incoming runoff and allows larger particles to settle. Forebays should conform to the design recommendations provided in Table B-8-2 and illustrated in Figure B-8-2.

Table B-8-2. Recommended specifications for extended detention forebay design

Component	Specification
Volume	10% of water quality volume (WQV)
Depth	2 – 5 feet deep, with a lateral slope of 1.0 – 1.5%
Berm/Weir Elevation	A rock or earthen berm, concrete weir, or gabion baskets should contain inflow up to the elevation of temporary ponding and diffuse overflow into main body of the wetland (overflow should not occur near side slopes and embankments); the height of the forebay berm embankment shall be at the elevation of the water quality volume.
Materials	The bottom or floor of the forebay should be concrete for ease of sediment removal; if necessary, inlet should be protected with energy dissipation structures.

EXAMPLE STEP 5: FOREBAY SIZING

From Step 1, the water quality volume is 25,864 cubic feet (cf)

Required forebay volume:

$$25,864 \text{ cf} \times 10\% = 2,586 \text{ cf}$$

2,586 cf x 120% = 3,103 cf. (Oversize by 20% to allow for sediment accumulation.) The desired depth is 3 feet. If we assume the forebay will have nearly vertical sides, then the approximate surface area of the forebay will be:

$$3,103 \text{ cf} / 3 \text{ ft} = 1,034 \text{ sf}$$

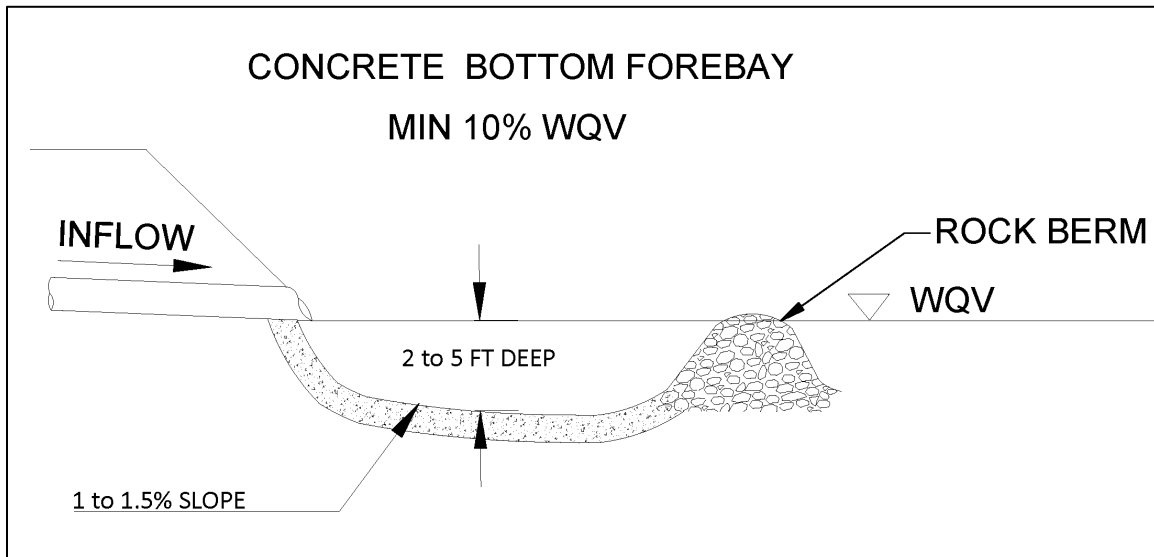


Figure B-8-2. Example 5- Sedimentation forebay

Step 6. Design Basin Flow Path and Zones

Flow Path

As mentioned in Step 3, the basin length to width, which is dependent upon the EDB flow path, should optimally be between 2:1 and 3:1. Use of berms, baffles, or swales may be incorporated to increase the effective length.



Figure B-8-3. Concrete trickle channel

Appendix B.8 Extended Detention Basins

Low Flow or Trickle Channel

The low flow or trickle channel will convey water from the forebay to the micropool, outlet, or other enhanced EDB feature. A longitudinal slope of .04 to 1% should be maintained for the low flow channel.

A concrete channel is recommended. A flat bottomed channel shape is recommended in order to facilitate maintenance by standard equipment (see Figure B-8-3). Riprap and soil riprap are not recommended as they can be damaged during sediment removal. Erosion protection may be needed at the downstream end of the low flow channel.

Basin Storage

Additional storage for flood control based on the appropriate local requirements should be provided. Capacity above the water quality volume may be designed using the calculated flow and volume requirements from local regulations. Using volumes and flows calculated, additional capacity can be added on to the water quality volume. The spillway for the EDB should be set based on the designed flood control volume surface elevation.

Basin Design

Side slopes for the embankments should be at a maximum of 3:1 side slopes, but optimally should be 4:1 or flatter. The entire basin should be designed with consideration towards maintenance access. A 10 foot access driveway at a maximum 5% slope to the pond and into the pond would allow for maintenance trucks and excavators to perform necessary maintenance activities. The access points should be designed with consideration to the geotechnical investigation. If reinforced access is needed, this will need to be incorporated into the overall pond design.

Micropool

The EDB design should include a small permanently ponded micropool. The micropool should be located directly in front of the outlet structure in the embankment of the EDB and requires side slopes of vertical walls or stabilized slopes of 3:1 (H:V). The micropool should be at least 2.5 feet in depth with a minimum surface area of 10 square feet. The bottom should be concrete unless a baseflow is present or anticipated or if groundwater is anticipated.

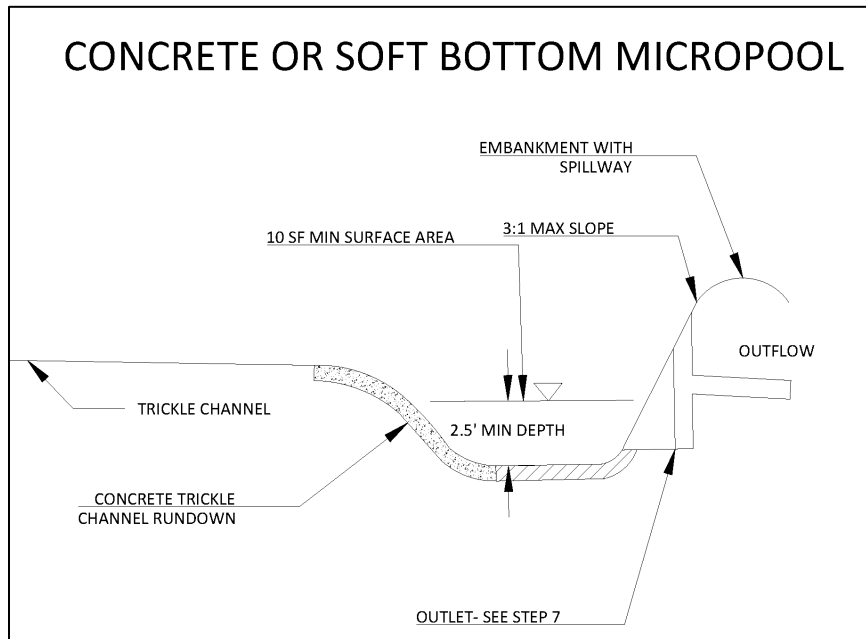


Figure B-8-4. Micropool configuration

Step 7. Select and Design Outlet/Bypass Method

For an EDB, the outlet structure is sized to control all design storms (based upon hydrologic routing calculations) and should consist of a riser with orifices designed to convey the design volume over a 48-hour period. Other control structures must be discussed with SARA. Small outlets that will be subject to clogging or are difficult to maintain are not acceptable.

Outlet and Trash Rack

The outflow structure should be sized to allow for complete drawdown of the water quality volume within at least 48 hours. Since sediment will tend to accumulate around the lowest stage outlet, the inside of the outlet structure for an EDB should be depressed below the ground level to minimize clogging due to sedimentation. Depressing the outlet bottom to a depth below the ground surface at least equal to the diameter of the outlet is recommended. No more than 50% of the water quality volume should drain from the facility within the first 24 hours. Most EDB outlet structures include an orifice plate for water quality discharge and a larger opening for discharging water at the flood control level. An orifice opening should typically be no smaller than 2.5 inches (unless a special non-clogging design is provided). A water-tight seal (rubber boot or equivalent) must be provided between all riser and pipe joint connections to minimize leakage. Seepage control or anti-seep collars should be provided for all outlet pipes. Additional outlets must be submitted to the San Antonio River Authority for approval.

An orifice is a circular or rectangular opening of a prescribed shape and size. The flow rate depends on the height of the water above the opening and the size and edge treatment of the orifice. For a single orifice, as illustrated in Figure B-8-5(a), the orifice discharge can be determined using the standard orifice equation below.

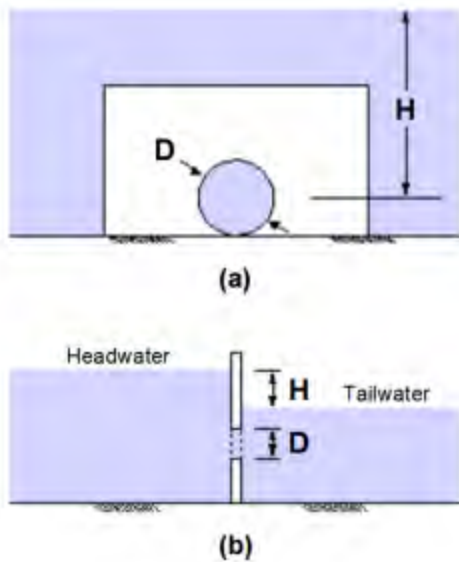


Figure B-8-5. Orifice definitions

$$Q = CA\sqrt{2gH} \quad \text{[Equation B-8-1]}$$

where: Q = discharge (cfs)

C = orifice coefficient

A = cross sectional area of orifice (ft²), computed using diameter “D” shown in Figure B-63

H = effective head on the orifice, from the center of orifice to the water surface (ft)

D = orifice diameter (ft)

g = gravitational acceleration (32.2 ft/s²)

The effective head at the orifice (H) varies depending on the tailwater condition. If the orifice discharges as a free outfall (See Figure B-8-5(a).), then H is measured from the center of the orifice to the upstream (headwater) surface elevation. If the orifice discharge is submerged (See Figure B-8-5(b).), then H is the difference in elevation of the headwater and tailwater surfaces as shown in Figure B-8-5(b).

Table B-8-3 below shows the orifice coefficient (C) for different configurations and edges.

Table B-8-3. Orifice coefficients for different configurations

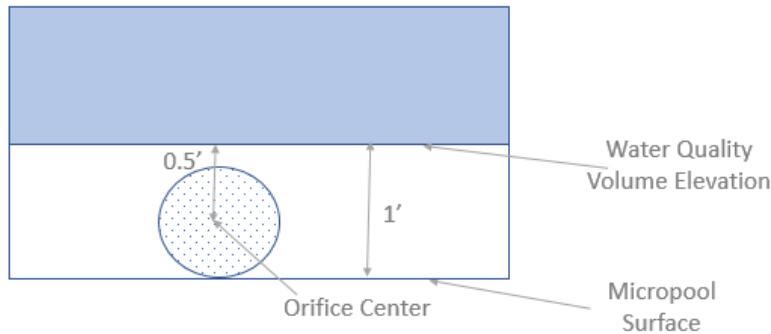
	Sharp Edged	Round Edged
Material Thickness < Orifice Diameter	0.6	0.92
Material Thickness > Orifice Diameter	0.8	

For square-edged entrance conditions the generic orifice equation can be simplified:

$$Q = 0.6A\sqrt{2gH} = 3.78D^2\sqrt{H} \quad \text{[Equation B-8-2]}$$

where: D = orifice diameter (ft)

H = Effective head at the orifice (ft) - See paragraph above.



Trash Racks

As shown in Figures B-8-7 and B-8-8, trash rack designs vary from case to case and many are designed specifically for the outlet structure they are placed around. In selecting a trash rack design, it is important to take maintenance access and safety into account. Ideally, outlet structures should be placed in or close to the basin embankment. Such a placement would allow the trash rack on the overflow opening to be sloped into the embankment. This enables access for maintenance and provides assistance for a child or small animal to climb up and away from the overflow outlet structure.

Trash racks must be large enough so that partial clogging will not adversely restrict flows reaching the control outlet. The surface area of all trash racks should be maximized and the trash rack should be located a suitable distance from the protected outlet to avoid interference with the hydraulic capacity of the outlet. The trash rack can be sized using the orifice and/or outlet size according to the relationship shown in Figure B-8-6. The location and size of the trash rack depend on a number of factors, including head losses through the rack, structural convenience, safety, and size of outlet.

Appendix B.8 Extended Detention Basins

The spacing of trash rack bars must be proportioned to the size of the smallest outlet protected. In many cases this means that the orifice plate will need a separate trash rack grate or screen to prevent the orifices from clogging, while a larger trash rack can be placed over the overflow opening or around the entire outlet structure. Spacing of the rack bars should be wide enough to avoid interference, but close enough to provide the level of clogging and safety protection required. In designing both the orifice screen and the overflow trash racks, it is important to consider how the racks will attach to the outlet structure.

Racks should be secured to the outlet in a manner that will allow maintenance personnel to remove any accumulated sediment or materials from behind the rack while at the same time avoiding gaps between the rack and the outlet structure. The trash rack should be located at a suitable distance away from the outlet, such that the hydraulic capacity of the outlet is not reduced due to interference.

The trash racks must have a combined total open area such that partial plugging will not adversely restrict flows through the outlet structure. A common rule-of-thumb is to provide a trash rack open area at least 10 times larger than the control outlet orifice (ASCE, 1992).

EXAMPLE STEP 7: SIZE THE TRASH RACK

Per City of San Antonio regulations, the hydrographs from the pond must match the pre-development hydrographs for the 5, 25, and 100 year events. Through an iterative process using a pond design software, a 24 inch pipe size has been selected in order to maintain the pre-development hydrographs while maintaining the minimum required 1 foot freeboard.

Given a 24-inch diameter outlet pipe, calculate the total grate open area on the overflow outlet trash rack.

1. Using Figure B-8-6, the ratio of grate open area: total outlet area at a diameter of 24 inches is 4:1
2. The total outlet area for a 24-inch pipe is:

$$\blacksquare A = \pi * \frac{2^2}{4} = 3.14 \text{ square feet (SF)}$$

3. Using the ratio 4:1, $4 * A_{\text{out}} = A_{\text{t}}$ so $4 * 3.14 = 12.56$ SF

Trash Rack Sizing

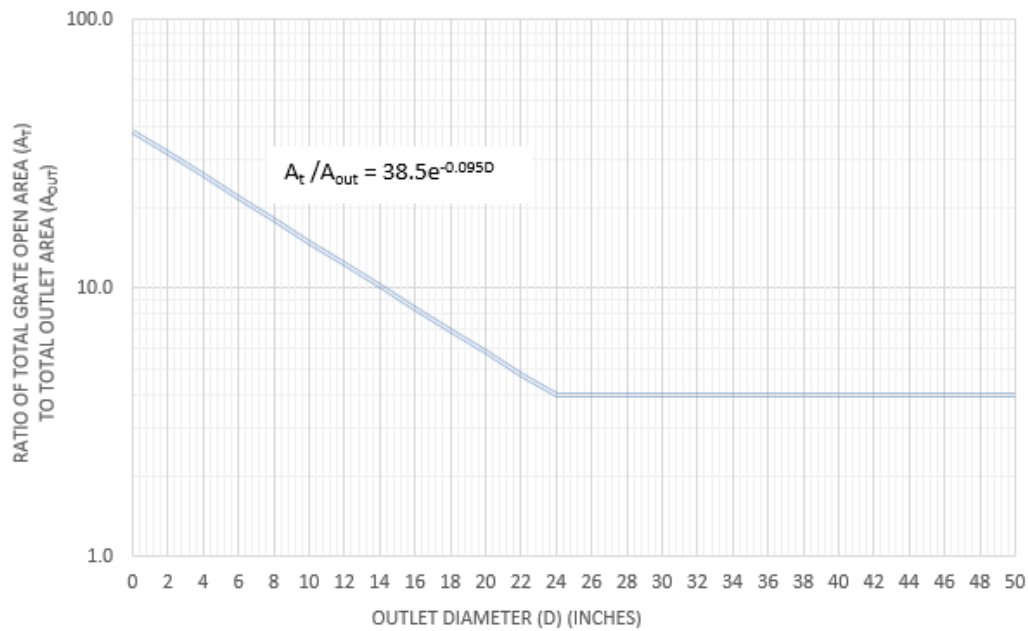


Figure B-8-6. Trash rack sizing



Figure B-8-7. Sloped trash rack with parallel wing walls. Source: Urban Drainage Flood Control District



Figure B-8-8. Vertical trash rack with flared wing walls. Source: Urban Drainage Flood Control District

Outfall and Emergency Spillway

Flared pipe end sections that discharge at or near the stream invert, as shown in Figures B-8-9 and B-8-10, are recommended. The channel below the pond outfall should be modified to conform to natural dimensions, and lined with large stone riprap placed over filter cloth. A silting basin may be required to reduce flow velocities from the primary spillway to non-erosive velocities (Barrett, 2005).



Figure B-8-9. Emergency spillway. Source: Randy Rath, the Huletts Current



Figure B-8-10. Outfall. Source: Cranberry Township, Pennsylvania

Minimum freeboard should be provided based on the appropriate local requirements, measured from the top of the water surface elevation for the extreme flood, to the lowest point of the dam embankment not counting the emergency spillway.

An emergency spillway must be included in the extended dry detention basin design to safely pass the design flood control event flood flow using the appropriate local standards. The spillway prevents pond water levels from overtopping the embankment and causing structural damage. The emergency spillway must be located so that downstream structures will not be impacted by spillway discharges.

The goal of designing the emergency spillway is to design a spillway which will not erode with the peak flow rate. The design process is iterative and is often conducted with software that simulates the flow rates of the design storm (most often a 100 year storm). The depth of a broad crested weir is adjusted until the design event is completely held by the weir structure and the velocity of the outflow does not erode the selected rip rap size. Once the depth of the weir is identified, account for the required freeboard. For more information consult local stormwater guidance. Stabilize the emergency spillway with non-erodible materials and provide energy dissipation as necessary.

The outfall should be adequately stabilized with energy-dissipation devices to prevent scour of downstream sediment (for energy dissipation configurations, see [Common Design Elements](#)). A pipe collar or other engineering solution should also be installed to prevent seepage of water through the soil along the edge of the pipe (Barrett, 2005). Riprap, plunge pools or pads, or other energy dissipators should be included at the downstream end of the outlet to prevent scouring and erosion. If the basin discharges to a channel with dry weather flow, care should be taken to minimize tree clearing along the downstream channel, and to reestablish a forested riparian zone in the shortest possible distance.

Step 8. Select Vegetation

Vegetation must be established before the basin is used. Established vegetation will provide erosion control and sediment entrapment. Wet tolerant species of diverse native and meadow grasses should be planted within the basin bottom, berms, and side slopes. Avoid planting turf grasses that require routine mowing on the side slopes and basin bottom unless safe access has been designed. Using a mix of native grasses and forbs can eliminate for routine mowing. Vegetation requiring irrigation is not recommended. A full plant list is included in Appendix E. Fertilizers and pesticides are not recommended. Compaction of soils at the bottom of the basin should be prevented to allow for healthy plant growth and infiltration.

A minimum 25-foot vegetative buffer area should extend away from the top of the pond slope in all directions. Although trees and shrubs can provide habitat, shade, and aesthetic benefits, take care to immediately remove woody vegetation from embankments and buffer to prevent geotechnical failures. Woody vegetation should not be planted or allowed to grow within 15 feet of the toe of the embankment as well.

Step 9. Design for Multi-Use Benefits

One of the primary benefits of the extended detention basin is the ability to provide combined water quality and flood control. Since some EDBs may not be considered as aesthetically pleasing as a stormwater wetland, additional features can be incorporated to generate additional uses for the extended basin. The following components can be incorporated into EDBs to promote multi-use benefits:

- Passive recreation, such as walking, biking, and wildlife observation, can be promoted by creating a multiple stage basin that will limit inundation of the passive recreation areas to one or two occurrences a year.
- Habitat for beneficial pollinators can be encouraged by creating diverse planting areas or incorporating wetlands into the EDB (note: it is important to consider potential pollutant loads from wildlife, such as indicator bacteria).
- Aesthetic appeal can be enhanced by creating flowing forms that appeared to be shaped by water, softening and varying slopes, shaping the basin bottom differently than the top, or using rocks for energy dissipation and adding them to other areas to avoid the actual energy dissipation from seeming out of place.

B.8.2 Critical Construction Considerations

B.8.2.1 Construction Plan Notes

To ensure that the EDB is constructed properly it is essential that the final construction documents include detailed notes in either the plans or specifications as appropriate. These notes should include items such as maximum allowable slopes (typically 3:1), pretreatment and erosion protection at all water entry points, planting schedules, specifications for all structures or proprietary devices, and any traffic and safety plans that may be necessary.

B.8.2.1.1 Site Preparation

Prior to beginning construction, the areas to be disturbed by construction or to be used as borrow locations must be cleared of trees, vegetation, roots, and any other materials. Soil stockpile locations must be graded to provide proper drainage and stabilized by seeding. Natural steep slopes such as those near channel banks should be re-graded to 1:1 or less. All trees within 15 feet of the embankment toe should be removed.

All soils that are used for the embankments and core trenches must either be approved by a geotechnical engineer or conform to GC, SC, CH, or CL by the Unified Soil Classification and have 30% passing the #200 sieve.

B.8.2.1.2 Structures and Propriety Devices

All structures and pre-fabricated devices must be installed to designer specifications. It is especially critical that orifices and overflow inverts are placed at the correct elevations. Trash racks must be properly installed so that no gap larger than the bar spacing is created between the outflow structure and the rack. Orifice screens should be installed so that the screen begins at the bottom of the micropool. This allows water to continue to enter the orifice plate even if clogging occurs due to floating debris.

B.8.2.1.3 Embankments

Embankments should be constructed per design specifications with a maximum allowable slope of 3:1. Areas with fill placement should be scarified prior to placing the fill lifts to improve adhesion. Fill should be placed in 8-12 inch lifts with each lift compacted with appropriate equipment prior to placement of the next lift.

B.8.2.1.4 Basin Geometry

All flow path lengthening features such as internal baffles must be constructed per the design to ensure that the basin flow length to width ratio is 2:1 or greater. The longitudinal slope of the low flow or trickle channel should be 0.4-1.0%.

B.8.2.1.5 Erosion Protection

Rip rap shall be placed below the outfall pipes and near the inflow point if necessary. Longitudinal slopes along the basin bottom shall not exceed 1%. Following construction, all exposed soils should be stabilized by hydroseeding or seeding under straw. Seeded areas must be tended until plants have established and reseeded if necessary.

B.8.2.2 Stormwater Pollution and Prevention Plan

During construction the extended detention basin must remain offline. Care should be given to design proper sedimentation precaution on-site during construction.

B.8.2.3 Provide Maintenance Access

To maintain EDBs, maintenance crews and equipment must occasionally access the forebay and micropool. The EDB design should incorporate a dedicated access easement from a public road to the basin and an appropriate maintenance staging area. The grading plan for the basin should incorporate access paths as appropriate for maintenance equipment to reach critical maintenance points including, for example, the forebay and outlet. The site geotechnical analysis will determine whether the access path must be stabilized to support heavy equipment.

B.8.3 Operation and Maintenance

Inspection and maintenance are key to ensure the proper function and aesthetics of EDBs. Table B-8-4 lists specific operation and maintenance tasks.

Table B-8-4. Inspection and maintenance tasks for extended detention basins

Task	Frequency	Indicator maintenance is needed	Maintenance Notes
Forebay inspection	Weekly or biweekly	Internal erosion or excessive sediment, trash, or debris accumulation	Check for sediment accumulation to ensure that forebay capacity is as designed. Remove any accumulated sediment.
Basin inspection	1 time/year	Cracked, eroded, or broken structural components	Repair basin inlets, outlets, forebays, low flow channel liners, and energy dissipaters when damage is discovered
Outlet inspection	After major storm events	Accumulation of litter and debris in basin area, large debris around outlet, internal erosion	Remove litter, leaves, and debris to reduce the risk of outlet clogging and to improve facility aesthetics. Erosion should be repaired and stabilized.
Mowing	2 times/year	Overgrown vegetation on embankment or adjacent areas	Frequency depends on location and desired aesthetic appeal
Embankment inspection	1 time/year	Erosion at embankment	Repair eroded areas and revegetate.
Vegetation	1 time/year	Dead plants; Woody growth on embankments	Within the first year, 10% of plants can die. Survival rates increase with time. Remove trees that encroach embankment toe, top, and buffer area.
Temporary watering	1 time/2–3 days for first 1–2 months	Until establishment and in severe drought	After initial year, if there is severe drought, watering might be required.
Nuisance control	Biweekly or as needed	Animals, feces, or burrows evident in or around EDB; Odor.	Employ qualified wildlife management professionals if needed. Remove conditions that create odors.
Fertilization	1 time initially	Upon planting	One-time spot fertilization for first year vegetation if needed.

B.8.4 References

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Appendix B.8 Extended Detention Basins

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B.9 Cisterns



Cisterns at Cliff Morton Development and Business Services Center, San Antonio, Texas. Source: Bender Wells Clark Design

B.9.1 Design

The design of a cistern or rain barrel can be broken down into an eight-step process, as listed in Table B-9-1. Additional resources are provided in TCEQ (2011), Texas Water Development Board (2005), and Texas A&M AgriLife Extension Services (2013).

Table B-9-1. Iterative design step process

Design step	Design component/ consideration	General specification
1 Determine BMP Size (B-139)	Use Appendix A	
2 Determine BMP Configuration (B-139)	Based on volume and desired alternative uses, incorporate next to buildings or underground. A foundation of gravel should be provided if the weight of the cistern at capacity is less than 2,000 pounds, otherwise a concrete foundation should be provided.	
3 Select and Size Inlet Configuration (B-142)	Conveyance type	Runoff should be conveyed to the cistern such that no backwater onto roofs occurs during the 100-year event. Two types of inlet configurations are available: <ul style="list-style-type: none"> • Dry conveyance: conduit freely drains to cistern with no water storage in pipe • Wet conveyance: a bend in the conduit retains water between rainfall events
4 Design Inlet Pretreatment Configuration (B-146)	Inlet filter	A self-cleaning inlet filter should be provided to strain out large debris such as leaves. Some systems incorporate built-in bypass mechanisms to divert high flows.
	First flush diverter	A passive first flush diverter should be incorporated in areas with high pollutant loads to capture the first washoff of sediment, debris, and pollen during a rainfall event. First flush diverters are typically manually dewatered between events.
5 Select and Design the Outlet and Overflow/Bypass Method (B-148)	Low-flow outlet	An outlet should be designed to dewater the water quality storage volume to a vegetated area in 2 days minimum. The elevation of the outlet depends on the volume of water stored for alternative purposes.
	Overflow or bypass	Emergency overflow (set slightly below the inlet elevation) or bypass must be provided to route water safely out of the cistern when it reaches full capacity.
6 Specify Cautionary Signage, Pipe Color, and Locking Features (B-151)	Signage	Signage indicating: "Caution: Reclaimed Water, Do Not Drink" (preferably in English and Spanish) must be provided anywhere cistern water is piped or outlets.
	Pipe color and locking features	All pipes conveying harvested rainwater should be Pantone color #512 and be labeled as reclaimed water. All valves should feature locking features.
7 Design for Multi-Use Benefits (B-152)	Harvested rainwater should be used to offset potable water uses, such as irrigation, toilet flushing, car washing, etc. Additionally, educational signage and aesthetically pleasing facades should be specified.	

Design step	Design component/ consideration	General specification
8 Additional Design Specifications (B-152)	Vector control	All inlets and outlets to the cistern must be covered with a 1-mm or smaller mesh to prevent mosquito entry/egress
	Routing water for use	Regardless of gravity or pumped flow, adequate measures must be taken to prevent contamination of drinking water supplies
	Cistern material	Tanks should typically be opaque to prevent algal growth.

Step 1. Determine BMP Size

The volume of water to be treated will help managers determine the appropriate cistern size and configuration. Methods for calculating the volume required for treatment are outlined in Appendix A. The treatment volume must be treated on-site and can be treated by multiple BMPs. Cisterns will typically be part of a treatment system that would include cisterns and other BMPs including bioretention or pervious pavement. The cistern could be included to reduce the size of another BMP. Peak runoff flow rates should also be calculated using the methods in Appendix A, *San Antonio Unified Development Code*, or *San Antonio River Basin Regional Modeling Standards for Hydrology and Hydraulic Modeling* such that pipes can be sized accordingly to allow overflow or bypass of the 100-year peak discharge.

Step 2. Determine BMP Configuration

Cisterns are available commercially in numerous sizes, shapes, and materials. Many are made to custom fit the available space and can be short and wide, tall and narrow, round, rectangular, and almost any size imaginable. They can be made from multiple materials but are primarily constructed of plastic or metal. Plastic cisterns can be covered with wood facades to provide a more finished appearance or can be painted with any image desired.

Cisterns are usually intended to capture runoff from elevated surfaces, such as rooftops, and, therefore, must be next to structures where runoff can be collected. Cisterns are typically designed to capture runoff from concentrated sources or collection systems such as a downspout. Multiple cisterns placed around a structure can be hydraulically connected to take advantage of maximum storage capacity. The typical components of a cistern are shown in Figure B-9-1.

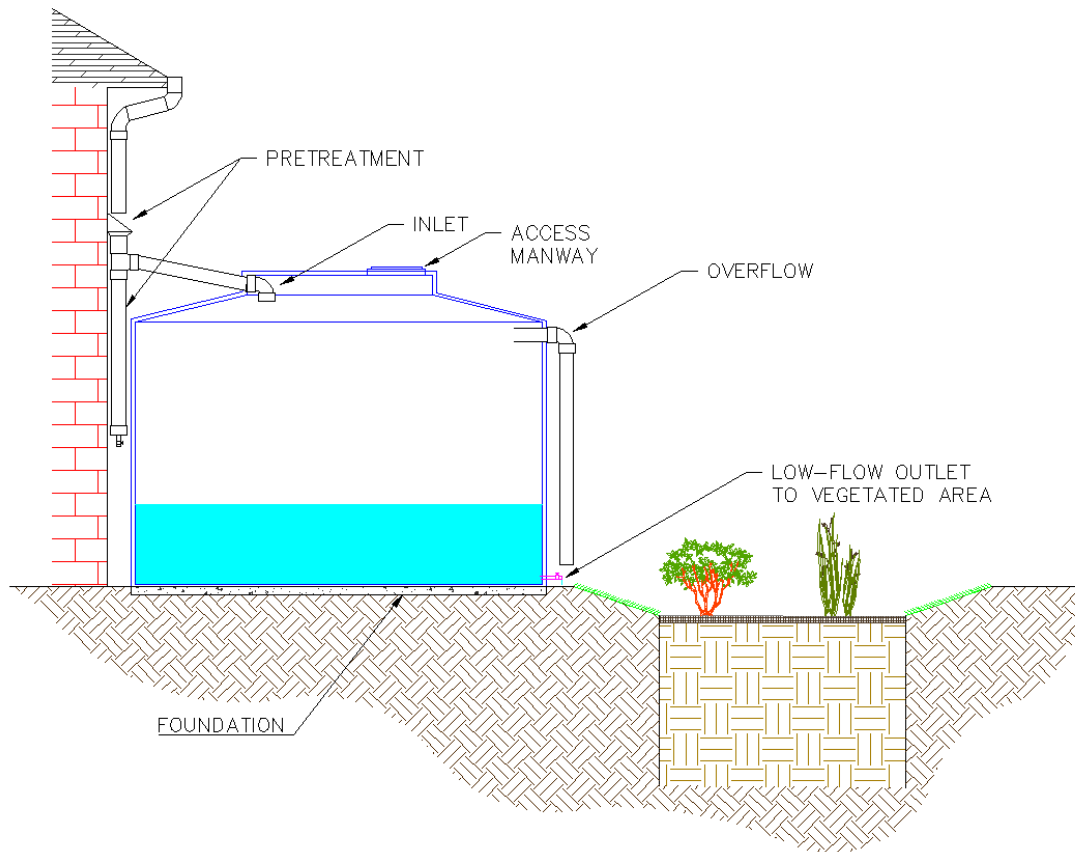


Figure B-9-1. Minimum design components of rainwater harvesting system

The conditions or layout of the site could determine if the foundation can be excavated and what materials will be used to support the cistern. Cisterns, especially large systems, must have a proper foundation to support the weight when they are at capacity. Two options exist for foundations (Jones and Hunt 2008):

- Cisterns exerting less than 2,000 pounds per square foot: The foundation of the cistern should be cleared and leveled. The foundation should be at least 6 inches of No. 57 gravel or concrete, depending on the stability of the underlying soils.
- Cisterns exerting greater than 2,000 pounds per square foot: The area beneath the cistern should be cleared and leveled. Concrete should be poured such that gravity flow can be maintained and the cistern can be drained to the level of the outlet valve.

The threshold where a concrete pad is required will vary depending on the soil type. If the structural capacity of the site to support a full cistern is in doubt, a geotechnical evaluation should be performed to determine the structural capacity of the soils. Figure B-9-2 to Figure B-9-3 shows the foundation options.



Figure B-9-2. Cistern less than 2,000 psi on a gravel foundation, New Bern, North Carolina. Source: North Carolina State University Department of Biological and Agricultural Engineering



Figure B-9-3. Cistern greater than 2,000 psi on a concrete foundation, Phil Hardberger Park, San Antonio, Texas.



Figure B-9-4. Construction of a concrete foundation for cistern at San Antonio River Authority Main Office, San Antonio, Texas.

Step 3. Select and Size Inlet Configuration

Inlet connections can feature either dry conveyance or wet conveyance. The following subsections describe each configuration.

Dry Conveyance

When downspouts freely drain to the cistern without any trapped water, the system uses dry conveyance. Connections can be made through the top of the cistern as shown in Figure B-9-5 and Figure B-9-6 or through the sides of the vertical portion formed for the opening of the cistern, often referred to as the manway, as shown in Figure B-9-7. Inlet connections made through the top of the cisterns can also include a basket filter as an inlet filter option. Inlet connections through the sides with the proper gaskets are recommended for ease of maintenance and access to the cistern.

When designing dry conveyance, downspout pipes should be sized to convey the 100-year discharge without causing any backwater on the roof.

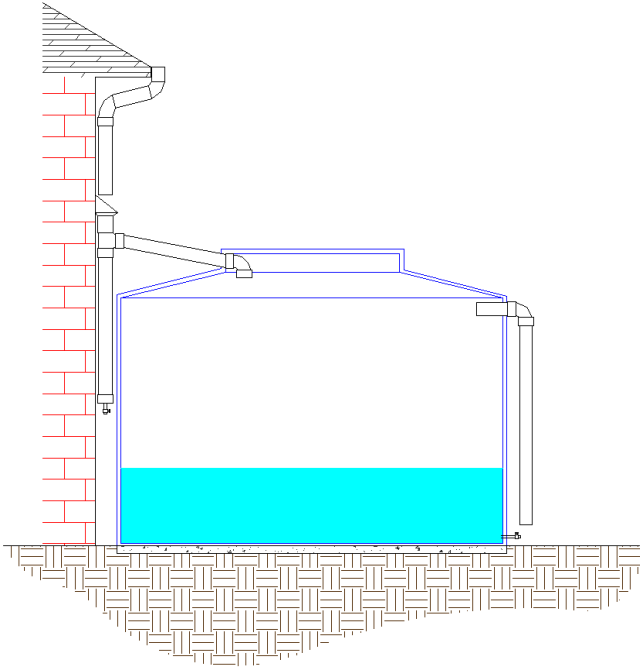


Figure B-9-5. Dry conveyance inlet configuration



Figure B-9-6. Inlet in the top of the cistern at Texas A&M University at San Antonio, San Antonio, Texas.



Figure B-9-7. Inlet in the sides of the man way, Greensboro, North Carolina. Source: Tetra Tech

Wet Conveyance

When the downspout features a bend, causing water to be trapped between runoff events, this system is known as wet conveyance (Figure B-9-8 and Figure B-9-9). Wet conveyance systems with buried downspouts can allow for cisterns to be placed further from buildings and might be preferable for aesthetic or overhead clearance purposes. When designing wet conveyance systems, the 100-year discharge from the catchment must be conveyed without any backwater onto the rooftop (considering all head losses through the pipe). Because water will permanently be stored in the downspout, watertight connections must be used to prevent leakage. A drain at the lowest elevation of the downspout can be installed, if desired, for dewatering and emergency maintenance.

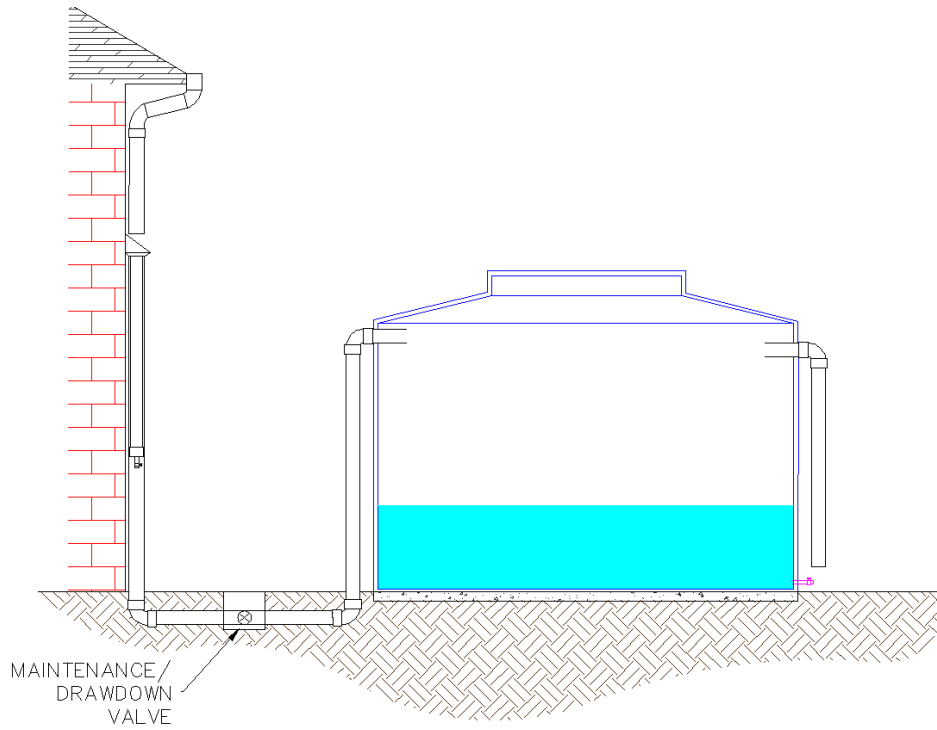


Figure B-9-8. Cistern with wet conveyance featuring a drawdown valve for maintenance



Figure B-9-9. Cistern with a wet conveyance inlet configuration, Dallas, Texas. Source: North Carolina State University Department of Biological and Agricultural Engineering

Step 4. Design Inlet Pretreatment Configuration

Stormwater runoff must be filtered before it enters the cistern to remove debris and particles that could clog the outlet. Two types of systems can be used: inlet filters and first-flush diverters. The following subsections discuss each pretreatment configuration in greater detail.

Inlet Filters

Inlet filters are designed to remove particles as runoff passes through the filters before entering the cistern; many filter options are available. The size and type of filter used will depend on the size of the area draining to the downspout. The filters can be installed at the gutter as shown in Figure B-9-10 or at the end of the downspout as shown in Figure B-9-11 depending on the configuration of the downspouts. Flow through filters that force all the runoff through the filter can be used for smaller drainage areas (less than 1,500 square feet). Filters capable of bypassing larger event flow could be required for larger drainage areas (1,500 to 3,000 square feet). A self-cleaning screen used for inlet filters should provide a minimum angle of declination of at least 45 degrees from horizontal, but angles of more than 45 degrees tend to enhance self-cleaning and prevent clogging (Nel 1996). Examples of two types of filters are shown in Figure B-9-12 and Figure B-9-13.



Figure B-9-10. Inlet filter at the gutter at San Antonio River Authority Main Office, San Antonio, Texas.



Figure B-9-11. Inlet configuration at the downspout at San Antonio River Authority Main Office, San Antonio, Texas.



Figure B-9-12. Flow-through inlet filter. Source: Tetra Tech

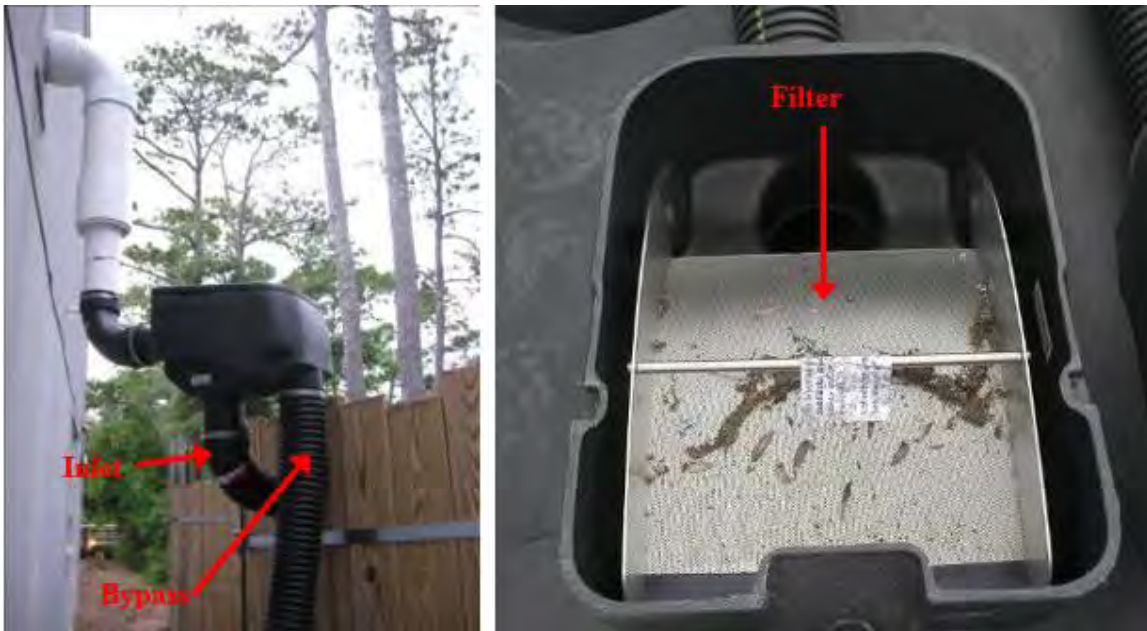


Figure B-9-13. Self-flushing filter with a bypass. Source: Tetra Tech

Appendix B.9 Cisterns

First Flush Diverter

First-flush diverters can be installed after the inlet filter and are designed to divert an initial volume of water away from the cistern to prevent small particles—initially washed off of the roof—from clogging the outlet. First-flush diverters are typically attached to the inlet or, in some cases, the inlet filter with a 4- to 6-inch diameter pipe with a small relief valve from which water can be diverted. The volume of water diverted away from the cistern depends on the length of the pipe. Once the diverter is full, a valve closes and water flows into the cistern. A first-flush diverter is not always required and inclusion is up to the designer depending on site conditions. A first-flush diverter is recommended for sites where pollen or other fine particles might not be removed by an inlet filter. Diverters must be routinely drained to provide capacity for the next runoff event.

Step 5. Select and Design the Outlet and Overflow/Bypass Method

Low Flow Outlet

The outlet of the cistern should be designed to release the volume of captured runoff at a rate below the design storm rate at its maximum capacity. The outlet of the cistern should be directed to a bioretention area or other pervious surface with enhanced infiltration capacity as demonstrated in Figure B-9-16. Irrigation area requirements for the Edwards Aquifer Recharge, Contributing, and Transition Zones are presented in Table B-9-2; these requirements are applicable to all areas.



Figure B-9-14. Valve for a first-flush diverter.
Source: North Carolina State University Department of Biological and Agricultural Engineering



Figure B-9-15. First-flush diverter configuration at the downspout at San Antonio River Authority Main Office, San Antonio, Texas.



Figure B-9-16. Cistern outlet into a planter box in San Diego, California. Source: Tetra Tech

Table B-9-2. Irrigation area requirements for cisterns in the Edwards Aquifer Recharge, Contributing, and Transition Zones (applicable to all areas)

Irrigation/infiltration area requirements
<ul style="list-style-type: none"> • 12 inches of soil cover, according to geotechnical investigation • 100 feet from wells, septic systems, natural wetlands, and streams • No sensitive or geologic features that could allow water to directly enter the aquifer • Coarse soil material (diameter greater than 0.5 inch) does not make up more than 30% of the soil volume • Slopes less than 10% • Soil permeability and surface area sufficient to produce no runoff

Source: Barrett 2005

The elevation of the low-flow outlet depends on the demand for alternative water use. When water demand and use is high (such as when the cistern is being used for toilet flushing, car washing, or consistent irrigation), the low-flow outlet can be placed such that half of the tank remains full for use. If stormwater management is the sole purpose of the cistern, the low-flow outlet should be placed at the bottom so that the tank can dewater and provide maximum capacity for storage of subsequent rain events. Figure B-9-17 illustrates example low flow outlet placement. Regardless of where the outlet is placed, temporary storage must be provided above the outlet elevation to capture the design storm volume. Models, such as the *Rainwater Harvester Design Model* (North Carolina State University 2008), can be used to optimize orifice placement.

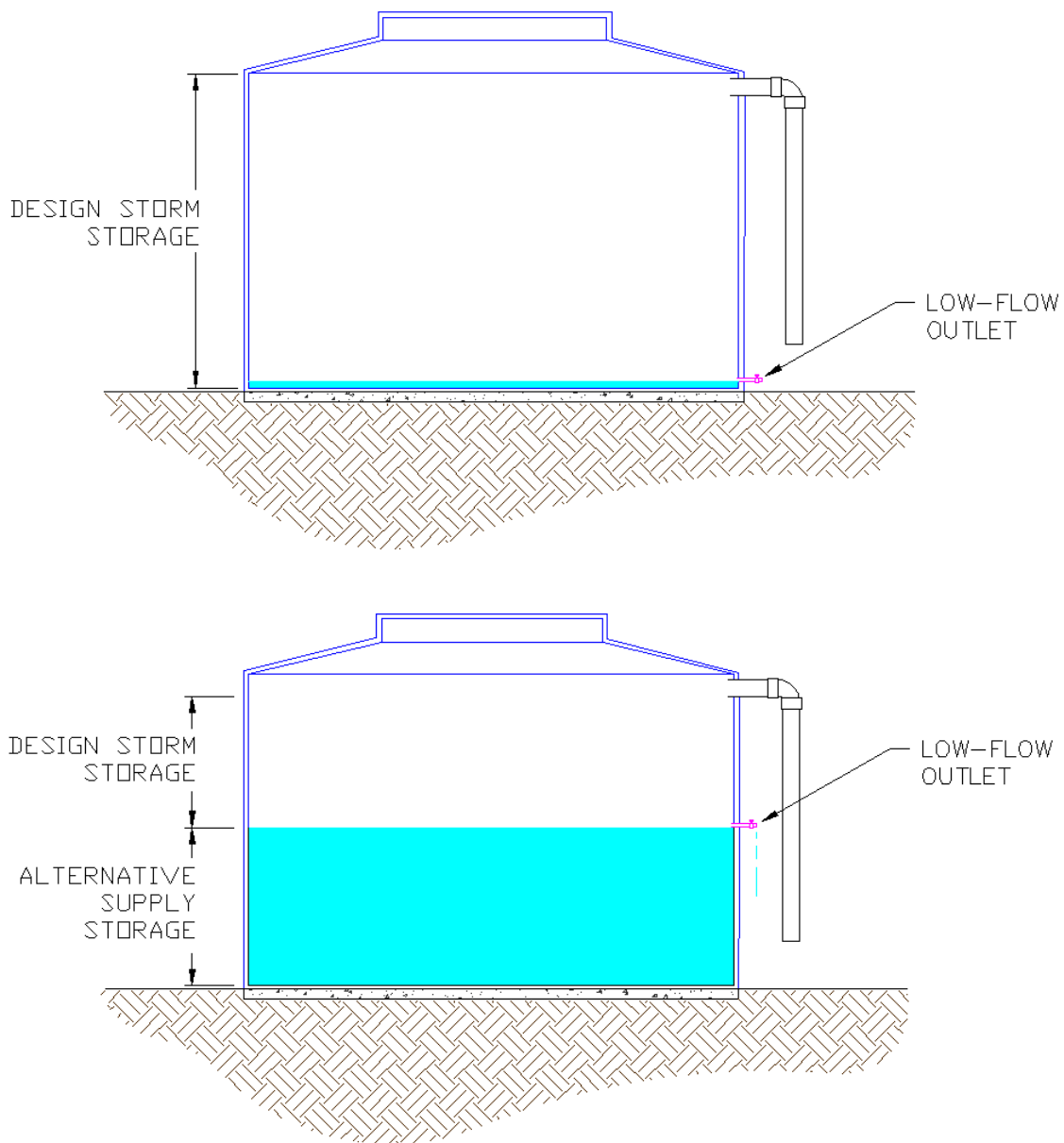


Figure B-9-17. Top: a flow outlet is placed to provide equal parts detention storage and storage for alternative use. Bottom: placing the low flow outlet at the bottom of the cistern ensures maximum design storm storage

Overflow or Bypass

All cisterns should have an overflow for runoff volumes that exceed the capacity of the cistern. The overflow should be set slightly below the inlet. Overflow connections should be connected to the tank using appropriate watertight gaskets. An additional bypass can be incorporated using an appropriate inlet filter. Examples of an overflow discharging to vegetated areas are provided in Figure B-9-18.



Figure B-9-18. A concrete channel (left) directs overflow away from the building at the Shavano Park Fire Station, Shavano Park, Texas; and a cistern overflows to an adjacent bioretention area lined with cobble (right) at Mission Library, San Antonio, Texas. Source: Bender Wells Clark Design

All overflow and outlet volumes should be directed safely away from all structural foundations and any areas where infiltration could have an adverse effect. Overflow and bypass mechanisms should be sized to safely convey the 100-yr discharge without any backwater onto the adjacent roof. Calculation of 100-yr conveyance should account for head losses through all pipe sections, elbows, entrances, and exits.

Step 6. Specify Cautionary Signage, Pipe Color, and Locking Features

Per Section 608.8 and Section C104.4 of the City of San Antonio amendments to the International Plumbing Code (City of San Antonio 2009), clear and obvious signage must be provided wherever harvested rainwater is used. Signs with purple background (Pantone color #512) and black lettering should read: “Caution: Reclaimed Water, Do Not Drink” in English and Spanish. Areas requiring signage include entrances to rooms (including mechanical rooms) where harvested water is piped or used, irrigation and automobile washing hoses, low-flow outlet orifices, toilet tanks that use harvested water for flushing, and any spigots, drawdown pipes, or access hatches. Specific signage language for these uses is provided in Section C104.7 of the City of San Antonio amendments to the International Plumbing Code. All pipes and hoses used to convey harvested water should be purple in color (Pantone color #512; Figure B-9-19) or continuously wrapped with purple mylar tape (per Section C104.4 of the City of San Antonio amendments to the International Plumbing Code; City of San Antonio 2009) to indicate that the water is not safe to drink. Tape-wrapped pipe shall display the warning provided above in nominal ½-inch black, uppercase lettering in two parallel lines such that after wrapping the pipe a full line of text is visible. Pipes that are completely colored purple shall display the warning on both sides at intervals not exceeding 3 feet. All valves (except fixture supply control valves) must be equipped with locking features.

Appendix B.9 Cisterns

In addition to preventing accidental ingestion, signage on cistern manways should restrict access to individuals with appropriate confined space credentials.



Figure B-9-19. Two cisterns with purple pipe connection at Phil Hardberger Park, San Antonio, Texas.

Step 7. Design for Multi-Use Benefits

By design, rainwater harvesting practices offer multi-use benefits by providing an alternative non-potable water source while controlling runoff volume and rate. In addition to hydrologic and water quality benefits, cisterns and rain barrels can be designed for multi-use benefits by

- Providing irrigation for landscape beds and vegetated stormwater practices
- Offsetting non-potable water supplies used for toilet flushing, car washing, swimming pools, street sweeping, and other uses (nonresidential cisterns only)
- Incorporating aesthetically pleasing colors, murals, or facades
- Incorporating creative downspout designs for small practices (rain chains)
- Raising public awareness of stormwater issues with signage

Step 8. Additional Design Specifications

The following considerations relevant to safety and water reuse should be included in design plan notes and specifications.

Vector Control

The inlets and outlets of cisterns and rain barrels should be covered with a simple piece of filter material, such as a screen or wire mesh, to prevent mosquito breeding. A 1 mm or smaller mesh is recommended. Screens at the inlet should be placed downstream of debris filters to prevent clogging by leaves. Overflow/bypass openings should be covered with a non-clogging configuration, such as a screen mesh flap that hangs across the pipe opening—the bottom of the flap should be weighted or attached with small magnets such that it remains closed when no flow is present, but can easily open to allow overflow when the tank is full.

Routing Water for Use

The method of routing water depends on the intended use. For basic irrigation, gravity can often be used to route harvested rainwater to nearby vegetation beds or infiltrating stormwater practices. To route water for use inside nonresidential structures or for greater distances from the cistern, a pump might be required. Submersible water pumps are commonly used, but pumps can also be installed in utility boxes next to the cistern. Pipes conveying harvested water may not be placed in the same trench as potable water pipes, a 2-foot horizontal separation must be maintained between harvested and potable water at all times. Buried potable water pipes that cross harvested water pipes must be at least 12 inches above the harvested water and must have a PVC sleeve that extends horizontally 2 feet to either side of the crossing. Harvested water should also be protected from contamination by sewer pipes in the same manner as potable water pipes (Section C104.3.3 of the City of San Antonio amendments to the International Plumbing Code; City of San Antonio 2009).

Appendix B.9 Cisterns

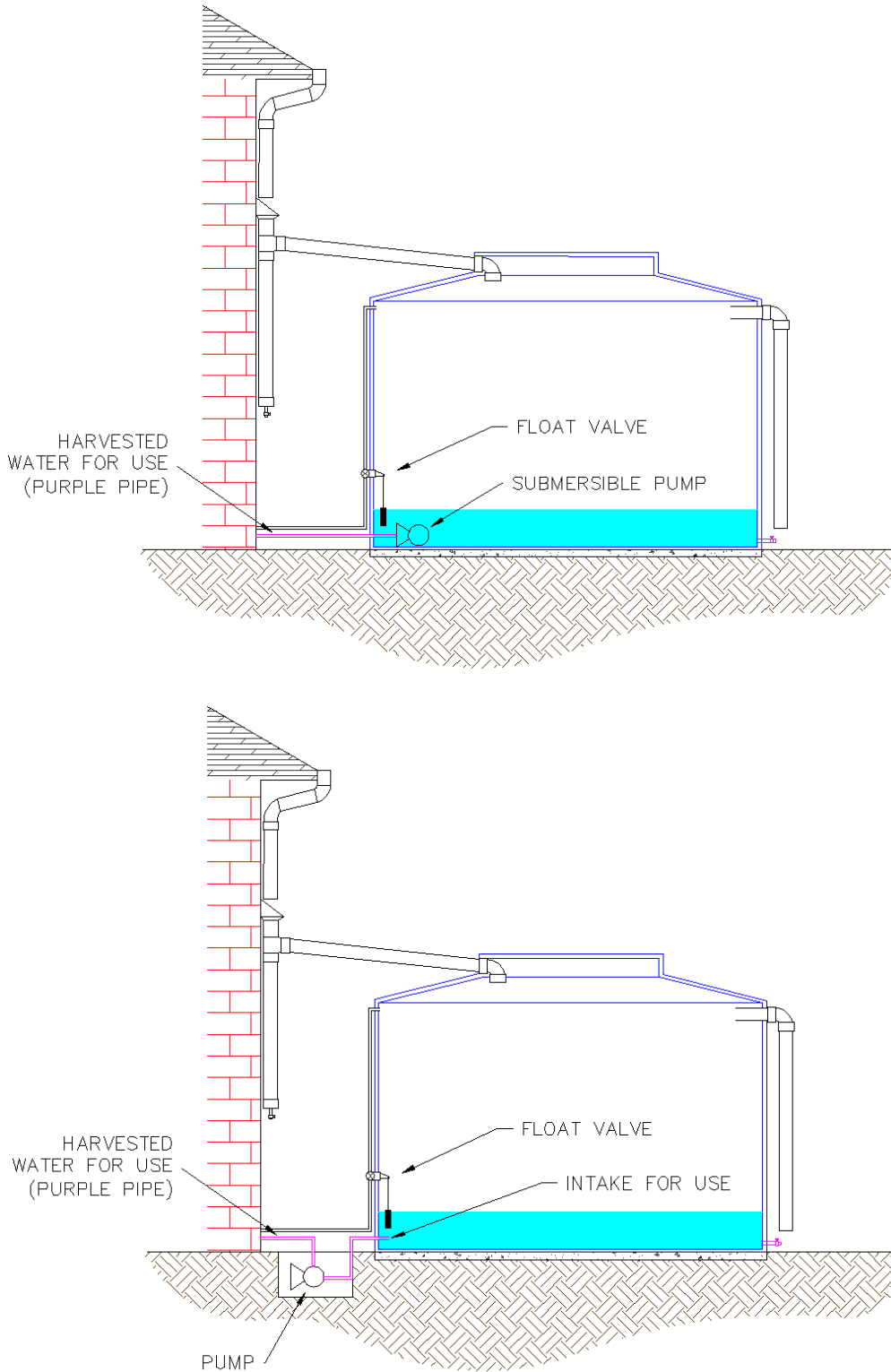


Figure B-9-20. Top: Conceptual schematic of cistern with submersible pump. Bottom: conceptual schematic of cistern with external pump

Cistern Material Specification

Rainwater harvesting tanks are typically constructed of plastic, metal, or concrete. The specified material will affect the quality of captured runoff, aesthetics, configuration, installation, and cost. Plastic tanks can experience algal growth if not completely opaque. In general, cisterns are expected to last 20 to 50 years (Kowalsky and Thomason 2011). A detailed description of cistern materials is provided in Texas Water Development Board (2005).

B.9.2 Critical Construction Considerations

Cisterns and rain barrels can present safety hazards if improperly designed. Engineers should direct contractors to implement appropriate OSHA health and safety protocol when installing cisterns. Elevated rain barrels and tall cisterns should be securely anchored to prevent toppling and subsequent injury.

B.9.3 Volume-based Method 1

Two runoff volume calculation methods are used throughout the region and are adopted in this analysis

Cisterns require regular maintenance during the rainy season to ensure proper function. Table B-9-3 lists specific tasks which are described below:

1. The main source of debris in the cistern is leaf litter and other detritus collected in the gutter system. The gutter systems should be inspected and cleaned. Any leaks should be immediately repaired.
2. Check inlet filters to prevent clogging and debris accumulation to allow for proper flow into the cisterns. Clean as needed to ensure proper operation.
3. Outlet pipes and fittings should be inspected to verify proper flows from the cistern. Cisterns should empty within 24 to 48 hours.
4. Overflow systems should direct water away from any structural foundations.
5. Cisterns should be checked for structural stability and secured as necessary.
6. It is possible for some sediment and debris to accumulate in the bottom of the cistern. Access to the cistern should be maintained, and it is necessary to conduct a visual inspection to verify debris in the cistern.

When harvested rainwater is used to replace non-potable water demand, inspections must occur upon installation and annually to ensure proper function of backflow preventers (per City of San Antonio amendments to the International Plumbing Code).

Appendix B.9 Cisterns

Table B-9-3. Inspection and maintenance tasks for cisterns

Task	Frequency	Indicator maintenance is needed	Maintenance notes
Gutter and rooftop inspection	Biannually and before heavy rains	Inlet clogged with debris	Clean gutters and roof of debris that have accumulated, check for leaks
Remove accumulated debris	Monthly	Inlet clogged with debris	Clean debris screen to allow unobstructed stormwater flow into the cistern
Structure inspection	Biannually	Cistern leaning or soils slumping/eroding	Check cistern for stability, anchor system if necessary
Structure inspection	Annually	Leaks	Check pipe, valve connections, and backflow preventers for leaks
Add ballast	Before any major wind-related storms	Tank is less than half-full	Add water to half full
Miscellaneous upkeep	Annually		Make sure cistern manhole is accessible, operational, and secure

B.9.4 References

- Barrett, M.E. 2005. *Complying with the Edwards Aquifer Rules. Technical Guidance on Best Management Practices*. RG-348. Prepared for Texas Commission on Environmental Quality, Field Operations Division, Austin, TX.
- City of San Antonio. 2009. Appendix C Gray Water Recycling Systems and Reclaimed/Recycled Water Systems. *2009 International Plumbing Code and 2009 International Fuel Gas Code/Local Amendments*. San Antonio, TX.
- Jones, Matthew P and Hunt, W.F. 2008. *Rainwater Harvesting: Guidance for Homeowners*. North Carolina Cooperative Extension, Raleigh, NC.
- Kowalsky, G., and K. Thomason. 2011. *Cistern Design Considerations for Large Rainwater Harvesting Systems*. <http://rfcd.pima.gov/pdd/lid/pdfs/cistern-design-for-water-harvesting.pdf>.
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B.10 Vegetated Swales



Vegetated swale at Madison High School Agriscience Building, San Antonio, Texas. Source: Bender Wells Clark Design

B.10.1 Design

Vegetated swales can be used as pretreatment for other stormwater BMPs or in a treatment train, but they should not typically be installed as standalone practices for water quality improvement. For water quality swale design, see [Bioswales](#). The design of vegetated swales can be broken down to an eight-step process (summarized in Table B-10-1).

Table B-10-1. Iterative design step process

Design step	Design component/ consideration	General specification
1 Determine Design Flows (B-159)	Use Appendix A and local guidelines	
2 Adjust Preliminary Swale Layout to Fit Site (B-160)	Swale dimensions	Determine allowable swale dimensions per site constraints
3 Calculate Swale Cross Sectional Dimensions (B-160)	Bottom width, side slopes, and longitudinal slope	Design flow depth should not exceed two-thirds the height of vegetation for optimum pretreatment
4 Determine Water Quality Design Flow Velocity (B-161)	Design velocity	Velocity should be less than 1 ft/s to reduce risk of erosion
5 Calculate Swale Length (B-161)	Residence time	If designed for water quality improvement, the hydraulic residence time should be at least 10 minutes to promote sedimentation
6 Provide Conveyance Capacity for Flows Higher than the Design Storm (B-162)	25-year, 24-hour storm	The 25-year, 24-hour storm should be conveyed at less than 3 ft/s to prevent erosion
7 Determine if Soils Need to be Amended (B-162)	If additional water quality improvement and infiltration are desired, amend the soil with minimum 2 inches of soil media (for media standards, see bioretention)	
8 Select Vegetation (B-162)	Native, noninvasive turf grasses (not bunch grasses) should be planted and maintained at a minimum height of 4 inches (see Appendix E)	

Step 1. Determine Design Flows

Swales are conveyance, flow-based BMPs, so treatment is based on a water quality design flow. The flow associated with the water quality design storm should be calculated based on information provided in Appendix A, *San Antonio Unified Development Code*, or *San Antonio River Basin Regional Modeling Standards for Hydrology and Hydraulic Modeling*. In addition to the water quality design flow, the vegetated swale should be designed to safely convey the 25-year storm event unless a diversion structure is installed to allow only the water quality flow into the swale (for details on diversion structures, see [Common Design Elements](#)).

Step 2. Adjust Preliminary Swale Layout to Fit Site

Vegetated swales can be in many different areas, particularly road sides, around parking lots, medians, and open areas. The linear structure of swales favors their use in the treatment of runoff from highways, residential roadways and common areas in residential subdivisions, along property boundaries and in and around parking lots. If permitted, vegetated swales are an excellent alternative to curbs and gutters, providing water quality and quantity benefits and adding an aesthetic appeal. Generally, a vegetated filter strip or buffer should be placed between the roadway and the vegetated swale to limit the amount of sediment entering the swale.

Step 3. Calculate Swale Cross Sectional Dimensions

The flow capacity of a vegetated swale is a function of the longitudinal slope (parallel to flow), the resistance to flow (e.g., Manning's roughness), and the cross-sectional area. The cross section is normally approximately trapezoidal, and the area is a function of the bottom width and side slopes. The flow capacity of vegetated swales should be such that the design water quality flow rate will not exceed a flow depth of two-thirds the height of the vegetation in the swale or 4 inches at the peak of the water quality design storm intensity.

The design procedure detailed below uses an iterative method for solving Manning's equation for a trapezoidal, open channel when the longitudinal channel slope, Manning's roughness, and design flow rate are known. The general Manning's equation is as follows, assuming the design flow rate is Q_{wq} :

$$Q_{wq} = \left(\frac{1.49}{n} \right) A R^{\frac{2}{3}} S^{\frac{1}{2}} \quad \text{[Equation B-10-1]}$$

where:

Q_{wq} = design storm flow rate (cfs)

n = Manning's roughness coefficient (no units)

A = cross-sectional area of flow (ft²)

R = hydraulic radius (ft) = area (A) divided by wetted perimeter (P)

P = wetted perimeter, the perimeter that is in contact with the swale during the design flow

s = longitudinal channel slope (along direction of flow) (ft/ft)

For the purposes of the trial and error process presented below, Manning's equation can be rearranged as follows (Barrett 2005):

$$b = \frac{0.134Q}{y^{1.67} S^{0.5}} - zy \quad \text{[Equation B-10-2]}$$

where:

b = swale bottom width (ft)

y = depth of flow (ft)

z = side slope of swale in the form $z:1$ (should not exceed 3)

An iterative process is best used to determine the depth of flow, y , bottom width, b , and side slope, z . Trial values of bottom width, flow depth, and side slope should be used to determine A , P , and R for the swale's cross section until the equations are equal and the flow depth, bottom width, and channel side slope are within the guidelines established in the previous sections. The equations for A and R for a trapezoidal channel are provided below:

$$R = \frac{A}{P} \quad \text{[Equation B-10-3]}$$

$$A = (b + zd)d \quad \text{[Equation B-10-4]}$$

$$P = b + 2d(1 + z^2)^{0.5} \quad \text{[Equation B-10-5]}$$

Although slope is often determined by site conditions, the slope should not exceed 2% for optimum water quality performance. Check dams can be used to reduce the effective slope of a swale (see [Bioswales](#) and Barrett 2005 for check dam design information). While not required, spreadsheet or computer-based models with "goal seek" functions can assist with this analysis.

Step 4. Determine Water Quality Design Flow Velocity

The flow continuity equation should be used to calculate the design flow velocity through the swale:

$$V_{wq} = \frac{Q_{wq}}{A_{wq}} \quad \text{[Equation B-10-6]}$$

where:

$$Q_{wq} = \text{design flow (ft}^3/\text{sec)}$$

$$V_{wq} = \text{design flow velocity (ft/sec)}$$

$$A = (b + zd)d = \text{cross-sectional area (ft}^2\text{) of flow at the design depth, where } z = \text{side slope length per unit height with a maximum slope of 3:1.}$$

The swale should convey the design storm without the threat of erosion. If the design flow velocity exceeds 1 ft/sec, one or more of the design parameters (longitudinal slope, bottom width, or flow depth) must be altered to reduce the design flow velocity to 1 ft/sec or less. It is desirable to have the design velocity as low as possible, both to improve treatment effectiveness and to reduce swale length requirements.

Step 5. Calculate Swale Length

The residence time in a swale should be at least 10 minutes to optimize pretreatment and sediment removal, although this is not always feasible given certain site constraints. Use the following equation to determine the necessary swale length to achieve a hydraulic residence time of at least 10 minutes (600 seconds):

$$L = 600V_{wq} \quad \text{[Equation B-10-7]}$$

where:

$$L = \text{swale length (ft)}$$

Appendix B.10 Vegetated Swales

V_{wq} = design flow velocity (ft/sec)

If the swale is too long to fit in the site, the design parameters can be adjusted to provide the flow velocity required to meet the recommended residence time. Additionally, a sinuous pattern can be used to increase total swale length (and decrease bed slope) over a distance.

Step 6. Provide Conveyance Capacity for Flows Higher than the Design Storm

Vegetated swales are often designed as online systems that convey flows higher than the design storm flow but can be designed as offline systems incorporating a high-flow bypass or diversion structure upstream of the swale inlet. A high-flow bypass usually results in a smaller swale size. If a high-flow bypass is required, see details on designing diversion structures in [Common Design Elements](#) of this Appendix B.

If the swale will be designed as an online system, confirm that the swale can convey the post-development peak stormwater discharge rate for the 25-year, 24-hour storm event (or local surrogate). The post-development peak stormwater runoff velocity for the 25-year, 24-hour storm should be less than 3.0 ft/sec. If the 25-year, 24-hour peak flow velocity exceeds 3.0 ft/sec, increase the bottom width or reduce the longitudinal slope as necessary to reduce the peak flow velocity to 3.0 ft/sec or less. If the longitudinal slope is reduced, the swale bottom width must be recalculated and must meet all guidelines established in the previous section.

Step 7. Determine if Soils Need to be Amended

If enhanced infiltration and water holding capacity is desired, vegetated swale soils may be amended with 2 inches of soil media (for soil media specifications, see [bioretention](#)) unless the organic content is already greater than 5 percent. The soil media should be mixed into the native soils to a depth of 6 inches to prevent soil layering.

Step 8. Select Vegetation

Swales must be vegetated to provide adequate treatment of runoff via filtration. Vegetation, when chosen and maintained appropriately, also improves the aesthetics of a site. It is important to maximize water contact with vegetation and the soil surface. The following criteria should be used for selecting appropriate vegetation:

1. The swale area must be appropriately vegetated with a mix of erosion-resistant plant species that effectively bind the soil. A diverse selection of low-growing plants that thrive under the specific site, climatic, and watering conditions should be specified. A mixture of dry-area and wet-area grass species that can continue to grow through silt deposits is most effective. Native or adapted grasses are preferred because they generally require less fertilizer, limited maintenance, and are more drought resistant than exotic plants. When appropriate, swales that are integrated in a project can use turf or other more intensive landscaping, while swales that are on the project perimeter, in a park, or close to an open space area should be planted with a more naturalistic plant palette. Vegetation in the swale must be rooted before the wet season. If vegetation cannot be rooted in time, turf should be installed and properly stabilized.
2. Trees or shrubs can be used along the banks as long as they do not over-shade the turf—woody vegetation should generally be avoided in the bottom of the swale to prevent increased velocities as water flows around the trunks.
3. Above the design treatment elevation, a typical lawn mix or landscape plants can be used, provided they do not shade the swale vegetation.

4. Temporary irrigation is required if the seed is planted in spring or summer. Seed should be properly stabilized with straw or equivalent mulch. Drought-tolerant grasses should be specified to minimize irrigation requirements.
5. Sod is the most effective and efficient way to vegetate swales; ensure that sod remains adequately irrigated during establishment. Sod should be laid perpendicular to flow and staggered such that no preferential flow paths are created by the seams between sod rolls. To maximize incidental infiltration, sod should be sourced from facilities that do **not** grow sod in clay soils. Washed sod can be also be furnished if desired.
6. Vegetative cover should be at least 4 inches high, ideally 6 inches. Swale water depth will ideally be 2 inches below the height of the shortest plant species.

For a local plant list, see Appendix E.

B.10.2 Critical Construction Considerations

Accurate fine grading of vegetated swales is important to prevent nuisance ponding and subsequent vector issues. Care should be taken to ensure positive drainage by providing slopes of 0.5% or steeper. Proper erosion control procedures are also important to protect swales during vegetation establishment. Temporary erosion control blankets, mats, and/or mulch should be applied per the recommendations in Barrett (2005). Turf reinforcement matting may be necessary for high flow areas.

B.10.3 Operation and Maintenance

1. Inspect vegetated swales for erosion or damage to vegetation at least twice annually for offline swales, preferably at the beginning and end of the wet season. Additional inspection during the wet season(s) and after periods of heavy runoff is recommended. Each swale should be checked for debris and litter and areas of sediment accumulation (for a vegetated swale inspection and maintenance checklist, see Appendix F).
2. Inspect inlets for erosion and sediment accumulation twice annually. Remove sediment if it is blocking the entry of stormwater. After sediment is removed, vegetation replanting or reseeding might be required. Repair erosion immediately and stabilize.
3. Side slopes should be maintained to prevent erosion. Slopes should be stabilized and planted using appropriate vegetation when native soil is exposed or erosion is observed.
4. Swales should drain within 48 hours. If a gravel drainage layer is incorporated underneath the swale to promote infiltration, the layer should drain within 72 hours of the end of the storm. Till the swale if compaction or clogging occurs. The perforated underdrain pipe, if present, should be cleaned if necessary.
5. Vegetation should be healthy and dense enough for filtration while protecting underlying soils from erosion. Specific maintenance items for vegetation are listed in Table B-10-2 and consist of the following:
 - Vegetation, large shrubs, or trees that interfere with landscape swale operation should be pruned.
 - Fallen leaves and debris from deciduous plant foliage should be removed.
 - Grassy swales should be mowed to keep grass 4 to 6 inches high. Grass clippings should be removed, and mowing should be performed perpendicular to the direction of flow such that no preferential flow paths are created by ruts.

Appendix B.10 Vegetated Swales

- Invasive vegetation must be removed and replaced with noninvasive species.
 - Dead vegetation should be removed if it composes more than 10 percent of the area covered or when swale function is impaired. Vegetation should be replaced and established before the wet season to maintain cover density and control erosion where soils are exposed.
6. Check dams (if present) should control and distribute flow across the swale. Identify causes for altered water flow and channelization, and clear obstructions. If damaged, repair check dams and swale should.

The vegetated swale should be well maintained; trash and debris, sediment, visual contamination (e.g., oils), and noxious or nuisance weeds should be removed.

Table B-10-2. Inspection and maintenance tasks

Task	Frequency	Maintenance notes
Inlet inspection	Twice annually	Check for sediment accumulation and erosion in the swale.
Mowing	2–12 times / year	Frequency depends on location and desired aesthetic appeal.
Watering	1 time/2–3 days for first 1–2 months. Sporadically after establishment	If droughty, watering after the initial year may be required.
Fertilization	1 time initially	One-time spot fertilization for first year vegetation if needed.
Remove and replace dead plants	1 time/year	Within the first year 10% of plants can die. Survival rates increase with time.
Check dams	1 time before the wet season(s) and monthly during the wet season(s).	Check for sediment accumulation and erosion around or underneath the dam materials.
Miscellaneous upkeep	12 times/year	Tasks include trash collection, spot weeding, and removing mulch from overflow device.

B.11 Vegetated Filter Strips



Vegetated Filter Strip at Oak Hills Church, San Antonio, Texas. Source: Tetra Tech

B.11.1 Design

The primary function of vegetated filter strips is to maintain sheet flow of runoff for pretreatment and energy dissipation. The steps for designing vegetated filter strips are provided in Table B-11-1.

Table B-11-1. Iterative design step process

Design step		Design component/ consideration	General specification
1	Determine the Design Flow Rate (B-166)	Use Appendix A and local guidelines	
2	Determine Available Filter Strip Width and Slope (B-167)	Based on existing site conditions	
3	Determine Vegetative Cover (B-167)	Vegetation	Native, drought-tolerant turf grasses (not bunch grasses) should be maintained at a height of no less than 4 inches. See Appendix E.
4	Calculate the Design Flow Depth (B-167)	Design flow depth	Flow depth should be less than 1 inch to achieve effective water quality improvement
5	Calculate the Design Velocity (B-167)	Design velocity	Velocity should be less than 1 ft/s for the water quality event and less than 3 ft/s for the 25-year, 24-hour event
6	Calculate the Length of the Filter Strip (B-168)	Length and residence time	Filter strip length should provide for a 10-minute hydraulic residence time if substantial water quality improvement is desired.
7	Design the Level Spreader/Energy Dissipater if Needed (B-168)	Level spreader	A level spreader and energy dissipater must be designed if concentrated flows are present.
8	Determine if Soils Need Amending (B-168)	If additional water quality improvement and infiltration are desired, amend the soil with 2 inches of media (for media standards, see bioretention)	
9	Specify Signage (B-168)	Signage should identify filter strip as stormwater treatment practice and prohibit foot traffic and other activities that could compact or rut filter strip soils.	

Step 1. Determine the Design Flow Rate

Vegetated filter strips are conveyance, flow-based BMPs, so treatment is based on a water quality design flow. The flow associated with the water quality design storm should be calculated according to information provided in Appendix A, *San Antonio Unified Development Code*, or *San Antonio River Basin Regional Modeling Standards for Hydrology and Hydraulic Modeling*. In addition to the water quality design flow, the filter strip should be designed to safely convey the 25-year storm event.

Step 2. Determine Available Filter Strip Width and Slope

In some design cases, the filter strip width and slope are predetermined on the basis of existing conditions. However, in many cases, determining the final width and slope are part of the design process.

Step 3. Determine Vegetative Cover

Select vegetative cover for the filter strip that is appropriate for local soil and climate conditions. Considerations should include requirements for maintenance, irrigation, and fertilization. See [vegetated swale](#) vegetation specifications.

Step 4. Calculate the Design Flow Depth

Hydraulically, filter strips should be designed according to two primary criteria: maximum depth of flow and maximum flow velocity.

Depth of runoff flow generated by the design storm in the filter strip should be limited to less than or equal to 1 inch. The design configuration having the greatest effect on those design standards are the contributing watershed area, longitudinal slope (along the direction of flow), the resistance to flow (Manning's n), and the width and slope of the filter strip. The design flow depth (d) is calculated on the basis of the width and the slope (parallel to the flow path) using a modified Manning's equation as follows:

$$d = \left(\frac{Q_{wq} \times n_{wq}}{1.49ws^{0.5}} \right)^{0.6} \quad \text{[Equation B-11-1]}$$

where:

d = design flow depth (ft)

Q_{wq} = water quality design flow rate (cfs)

w = width of strip perpendicular to flow that equals the width of impervious surface contributing to the filter strip (ft)

s = slope (ft/ft) of strip parallel to flow, average over the whole width

n_{wq} = Manning's roughness coefficient (0.025–0.03)

If d is greater than 1 inch, a smaller slope is required, or the filter strip may not provide substantial water quality improvement.

Step 5. Calculate the Design Velocity

Maximum design storm flow velocity should be limited to 1 ft/sec. The design flow velocity is based on the design flow, design flow depth, and width of the strip as follows:

$$v_{wq} = \frac{Q_{wq}}{dw} \quad \text{[Equation B-11-2]}$$

where:

v_{wq} = water quality design flow velocity (ft/sec)

Q_{wq} = water quality design flow rate (cfs)

d = design flow depth (ft)

Appendix B.11 Vegetated Filter Strips

w = width of strip perpendicular to flow that equals the width of impervious surface contributing to the filter strip (ft)

Step 6. Calculate the Length of the Filter Strip

Determine the required length (L) to achieve a desired residence time of 10 minutes using this equation:

$$L = 600 v_{wq} \quad \text{[Equation B-11-3]}$$

where:

L = swale length (ft)

v_{wq} = design water quality flow velocity (ft/sec)

If the design parameters as computed in steps 1 through 6 above are not within the recommended standards, an alternative BMP, such as a grassed swale should be considered to treat stormwater runoff.

Step 7. Design the Level Spreader/Energy Dissipater if Needed

The transition of stormwater runoff from upslope, impervious areas to the gently sloping, vegetated surface of a filter strip is critical to the proper function of the BMP. Flow should not be concentrated and should not transition to flow over the filter strip such that it causes concentration or erosive flows. Where flow originates on roadways and parking lots, the designer can elect to incorporate an energy-dissipation device at the interface between the hardened pavement surface and the filter strip. Energy dissipaters typically take the form of a gravel flow spreader consisting of a gravel filled trench that is perpendicular to the direction of flow. The gravel flow spreader should have the following characteristics:

- The gravel flow spreader must be a minimum of 6 inches deep and 12 inches wide.
- The gravel surface should be a minimum of 1 inch below the surface of the adjacent pavement.

Vegetated filter strips are often used in combination with concrete level spreaders to provide energy dissipation.

Step 8. Determine if Soils Need Amending

If enhanced infiltration is desired, vegetated filter strips can be amended with 2 inches of soil media (for soil media specifications, see [bioretention](#) design chapter) or plant-derived compost unless the organic content is already greater than 5 percent. The amendment should be mixed into the native soils to a depth of 6 inches to prevent soil layering.

Step 9. Specify Signage

It is important to specify installation of signage so that the vegetated filter strip is properly maintained. Signage should label the practice as a stormwater BMP, prohibit foot traffic, and instruct maintenance crews to maintain vegetation at a height of approximately 4 inches—this will ensure maximum treatment and soil stabilization.

B.11.2 Critical Construction Considerations

The primary mechanism of failure for filter strips is the development of concentrated flow, which results in erosion and the formation of rills. Vegetated filter strips should thus be carefully graded to prevent concentration of flow and level spreaders (if used) should be completely level.

B.11.3 Operation and Maintenance

The primary maintenance requirement of a vegetated filter strip is managing vegetation in the filter strip. As a result, specialized equipment and training of maintenance crews is typically not necessary. Maintenance activities for vegetated filter strips are listed in Table B-11-2 and include the following:

- Regular mowing to maintain visual aesthetics. Grass height should be maintained at a minimum of 4 inches high. Clippings should be removed so flow is not impeded. Mowing should be performed perpendicular to the direction of flow to prevent preferential flow paths caused by wheel ruts.
- Remove accumulated sediment from the inlet lip of the vegetated filter strip when accumulation is obvious (monthly during seasons of heavy rainfall).
- Weeds and other vegetation should be removed as needed being careful not to cause pits or exposed soil that could lead to increased erosion.

Table B-11-2. Inspection and maintenance tasks

Task	Frequency	Maintenance notes
Mowing	2–12 times/year	As needed to maintain aesthetics. Grass height should be a minimum of 4 inches.
Inlet inspection	Once after first major rain of the season, then monthly during the rainy season(s)	Check for sediment accumulation to ensure that flow into the system is as designed. Remove any accumulated sediment.
Miscellaneous upkeep	12 times/year	Tasks include trash collection, spot weeding, and irrigation as necessary.

B.11.4 References

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B.12 Optimal Treatment Train Approach

This section describes the approach to layout BMPs for a treatment train system. Figure B-12-1 summarizes the recommended process and provides several important concepts that should be considered during identification of the BMPs within the treatment train system. The top of the figure shows four progressive levels of treatment (discussed further below). The Figure also lists applicable BMPs for each treatment level and identifies the associated unit processes. Figure B-89 only shows the BMP unit processes that act as major and/or optional function as identified in Table 3-2 in Chapter 3. As noted in the manual, to maximize treatment of stormwater runoff, the designer should choose combinations of BMPs with different unit processes that will improve pollutant removal.

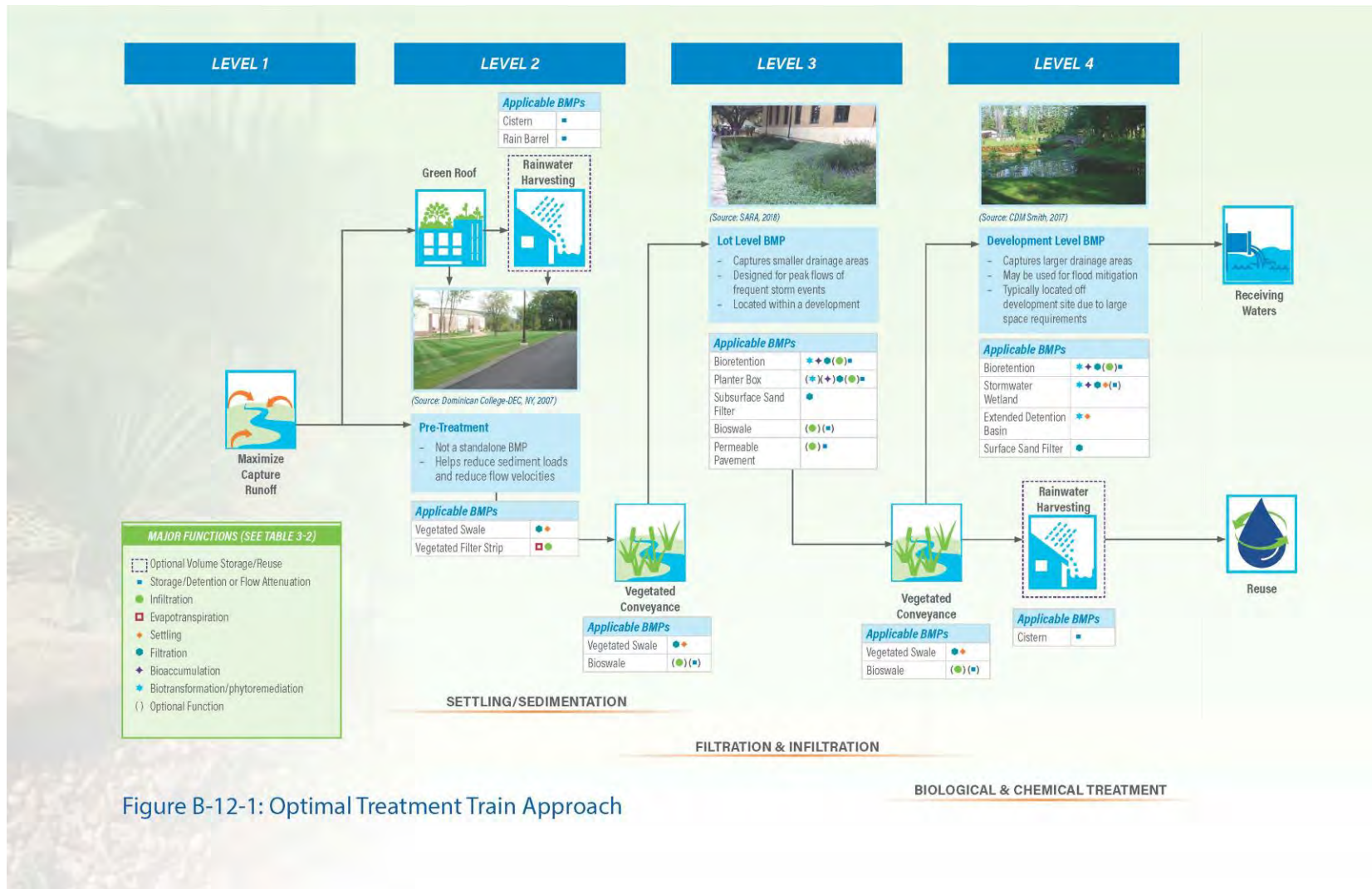


Figure B-12-1: Optimal Treatment Train Approach

Figure B-12-1. Optimal Treatment Train Approach

Appendix B.12 Treatment Trains

Each of the four levels of treatment shown along the top of Figure B-89 progressively enhance the treatment of stormwater. The first level (level 1) is to maximize runoff capture. The second level (level 2) is pre-treatment and conveyance with the option of including green roof or rainwater harvesting. The third level (level 3) is lot level BMPs that are intended to capture smaller drainage areas closer to the source of runoff (impervious cover) and are integrated into the development. The development level BMPs (level 4) are intended to treat larger drainage areas and are often larger BMPs that can be designed to also address water quantity. Additional information about each of the levels is provided below.

In addition, along the bottom of the figure is a preferred order for types of major functions. The first is settling and sedimentation to remove large sediment and debris. Next is filtration and infiltration to remove smaller suspended materials. The final type of functions is biological and chemical treatment to treat dissolved pollutants. Figure B-12-1 illustrates a recommended optimal sequencing approach to lay out treatment trains, but it's important to note that maximum treatment levels may not be achievable in all site conditions. If a treatment level is skipped, it may still be considered an acceptable treatment train; however, all levels of treatment should be considered prior to eliminating levels of treatment.

Level 1: Maximize Capture of Runoff

Consistent with Steps 4-6 from Section 1.6, minimize total and effective impervious area, maximize capture of stormwater runoff, and maximize treatment of pollutant load in specific lot level and development level BMPs. This level of treatment should consider conserving native areas to allow for stormwater runoff to infiltrate into vegetated areas prior to the treatment train system. All remaining runoff will be addressed by the treatment train.

Level 2: Pre-Treatment & Conveyance (or Rainwater Harvesting)

The next step for treatment can be a green roof, a rainwater harvesting BMP, or a pre-treatment BMP. Green roofs also have the ability to be connected with a rainwater harvesting BMP, including cisterns and rain barrels. During planning, when considering rainwater harvesting systems, consider the potential volume limitations and the impact on the treatment train system.

Pre-treatment and conveyance are primarily used as an initial step to remove debris and sediment and enhance the performance of downstream BMPs. Pre-treatment BMPs include vegetated filter strips and vegetated swales. These are not standalone BMPs and should be combined with a bioswale, lot level, or development level BMP. The BMPs that should be used for conveyance of stormwater include vegetated swales or bioswales. An additional pre-treatment option would be to include a sediment forebay in combination with a lot level or development level BMP to help remove debris and sediments.

Level 3: Lot Level BMP

Lot level BMPs typically serve smaller drainage areas and receive runoff from nearby impervious areas (e.g. parking lots, roadways, sidewalks). Infiltration and filtration BMPs are often used as lot level BMPs to remove suspended solids and sediment associated pollutants and reduce runoff volumes and peak flows near the source. These BMPs may also allow for biological and chemical treatment to remove dissolved or suspended pollutants. They are designed to collect and treat flows from the water quality event or frequent storm events. Types of infiltration and filtration BMPs are identified in Table 3-2 in Chapter 3. A lot level BMP typically provides flexibility for the site layout

to fit into areas that may have limited space available. Multiple lot level BMPs may be necessary to collect the desired stormwater runoff and may be placed in series or parallel depending on stormwater treatment requirements or other site conditions. If this level is skipped because the lot level BMP cannot be placed within the development, then pre-treatment and conveyance (level 2) may be discharged directly into a development level BMP (level 4).

Level 4: Development Level BMP (or Rainwater Harvesting)

Development level BMPs typically have larger tributary drainage areas and can also be used to mitigate water quantity. A development level BMP may collect stormwater from the source or be routed from lot level BMPs. Stormwater is typically detained in a development level BMP facility where it may also undergo biological and chemical treatment, as described in Step 7 of Section 1.6.2, prior to discharging into a receiving water body. Additionally, if a development level BMP is determined to not be necessary due to sufficient pollutant removal from lot level BMPs or is not feasible for a site, due to size requirements or other site conditions, the lot level BMPs (level 3) may be discharged directly into a receiving water body with appropriate discharge mitigation. Runoff from lot level BMPs may also be collected and stored for rainwater harvesting then reused.

Figure B-12-2 includes an example rendering for a treatment train in a residential setting. As shown in the example, each BMP in the treatment train may receive runoff from the upstream drainage area, another BMP, or both. This allows additional flexibility in the design of the systems. In this example, each house has a cistern that represents a level 1 BMP. Assuming that the cisterns are sized based on the rooftop that drains to the cistern and the water quality storm, any volume greater than that of the water quality storm or from an area not treated by the cistern would overflow and flow through a vegetated filter strip toward the vegetated swale (the swale functions as a vegetated conveyance BMP) or directly to the bioretention basin. Each of these BMPs would be sized based on the overflow from the cisterns in addition to the additional runoff (flow and volume) from the contributing area that is not captured by a cistern. Alternatively, to provide additional treatment, the vegetated swale could be designed as a bioswale that would be a level 3 BMP. The bioretention basin is a level 4 BMP that would handle flow from the entire development. The bioretention basin could function as the primary treatment for runoff not captured by the cisterns (diverted or overflows) and not treated by other BMPs. This would be the case if there was insufficient space or for other reasons that the cisterns or the swale were not sized for the water quality storm. The bioretention system could also provide an additional level of treatment for runoff discharged through any of the BMPs.



Figure B-12-2. Example of residential treatment train

Figure B-12-3 includes an example rendering for a treatment train system in a commercial setting. There are two types of BMPs that function as the initial BMPs in the treatment train system, the green roofs and permeable pavement. Each building in the example has a green roof (level 2). The parking lot has areas with permeable pavement (level 3) that does not receive flow from the green roof. The green roof and permeable pavement function as a first step for treatment and should be sized based on the drainage area or considering limitations of the available footprint. For several of the buildings, the discharge from the green roof mixes with stormwater from other surfaces and is conveyed into the vegetated swale (vegetated conveyance) and ultimately a sand filter (level 4). For another building, discharge from the green roof mixes with flow from other areas and flows directly to the sand filter. Again, this shows some of the flexibility of the treatment train. The permeable pavers also discharge to the vegetated swale and then the sand filter. As in the first rendering, the treatment train system provides a lot of flexibility for how the BMPs are sized and located. Although each BMP may not treat the entire water quality volume of its drainage area, subsequent BMPs in the series can treat additional runoff to help meet the water quality runoff for the site overall.



Figure B-12-3. Example of commercial treatment train

B.12.1 References

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B.13 Common Design Elements

Many BMPs have similar elements or standards. Those common elements and associated design standards are outlined in this section.

B.13.1 Geotechnical Investigation

The design of most BMPs will rely on an initial geotechnical investigation. Performing soil tests early in the conceptual and preliminary design phases will ensure that the proposed system is optimized to actual site conditions and to prevent costly change orders resulting from poorly estimated soil parameters.

The investigation should include both desktop and field analyses to fully characterize the structural and hydrologic characteristics of a site. Desktop analyses can be used to generate a conceptual site design but should always be verified with field investigation. The following parameters can be determined by desktop analyses:

- Underlying geology (especially presence of karst geology or shallow bedrock)
- Site location with respect to Edwards Aquifer Recharge Zone
- Proximity to steep slopes
- Proximity to structural foundations, roadway subgrades, utilities, and other infrastructure
- Proximity to water supply wells
- Proximity to septic drain fields

Field investigations should be performed by a licensed soil scientist or geotechnical engineer. All soil testing should be performed at the depth of the initially proposed subgrade because this is the soil strata where infiltration could occur. If a detention (non-infiltrating system) is proposed, soil tests must still be performed to determine structural requirements and to identify the elevation of the seasonal high water table.

Sufficient test pits or borings should be done to adequately characterize the site soil conditions, but, at a minimum, the greater of 2 samples or 1 sample per 50,000 square feet of BMP area should be collected. Soils should be investigated to a depth of at least 3 feet below the proposed BMP subgrade. The following key parameters should be determined or verified by field investigation:

- The infiltration rate of the soils at the potential subgrade (ASTM D 3385 *Standard Test Method for Infiltration Rate of Field Soils Using Double-Ring Infiltrometer*, or a comparable method)
- The depth and texture of subsoils
- The depth to the seasonal high groundwater table
- Structural capacity of soils (if surface BMP, such as cistern or planter box, is intended)
- Presence of expansive clay minerals
- Presence of compacted or restrictive layers
- Underlying geology (especially presence of karst geology or shallow bedrock)

Appendix B.13 Common Design Elements

- Proximity to steep slopes
- Proximity to structural foundations, roadway subgrades, utilities, and other infrastructure
- Proximity to water supply wells
- Proximity to septic drain fields

In the Edwards Aquifer Recharge, Contributing, and Transition zones, at least 12 inches of natural soil must be provided wherever a practice is intended to discharge stormwater for infiltration (e.g. permeable pavement in the Contributing Zone or irrigation with harvested water from a cistern). Fill material may be used, but it must have a texture comparable to natural site soils. All soils should contain no wastes, debris, deleterious material, or material that can leach contaminants. Soils should contain less than 30 percent coarse material by volume, which is defined as material larger than 0.5 inch in diameter.

B.13.2 Curb Cuts

When BMPs are incorporated into highly impervious areas, such as parking lots and in road rights-of-way, curb cuts can be required to allow surface runoff to enter the BMP. Curb cuts are designed such that the design storm can pass through the curbing without causing water to pond in the travel lanes. Example curb cuts are shown in Figure B-13-1 and Figure B-13-2.

Designs have the following recommendations:

- The opening should be at least 18 inches wide at the base to prevent clogging and to provide dispersed flow.
- The curb cut can have vertical sides or have chamfered sides at 45 degrees.
- Slope the bottom of the concrete curb cut toward the stormwater facility.
- Provide a minimum 2-inch drop in grade between the curb cut entry point and the finished grade of the stormwater facility.
- The curb cut must pass the design storm flow without causing backup that would disrupt normal travel in the lane.

The curb cut opening should be armored to prevent erosion. Concrete, stone, or sod can be used to armor the flow path to the base of the bioretention area. If a vegetated filter strip is provided downstream from the curb cut, a turf reinforcement mat may be required to stabilize the soil if flows are expected to exceed 3 ft/sec.

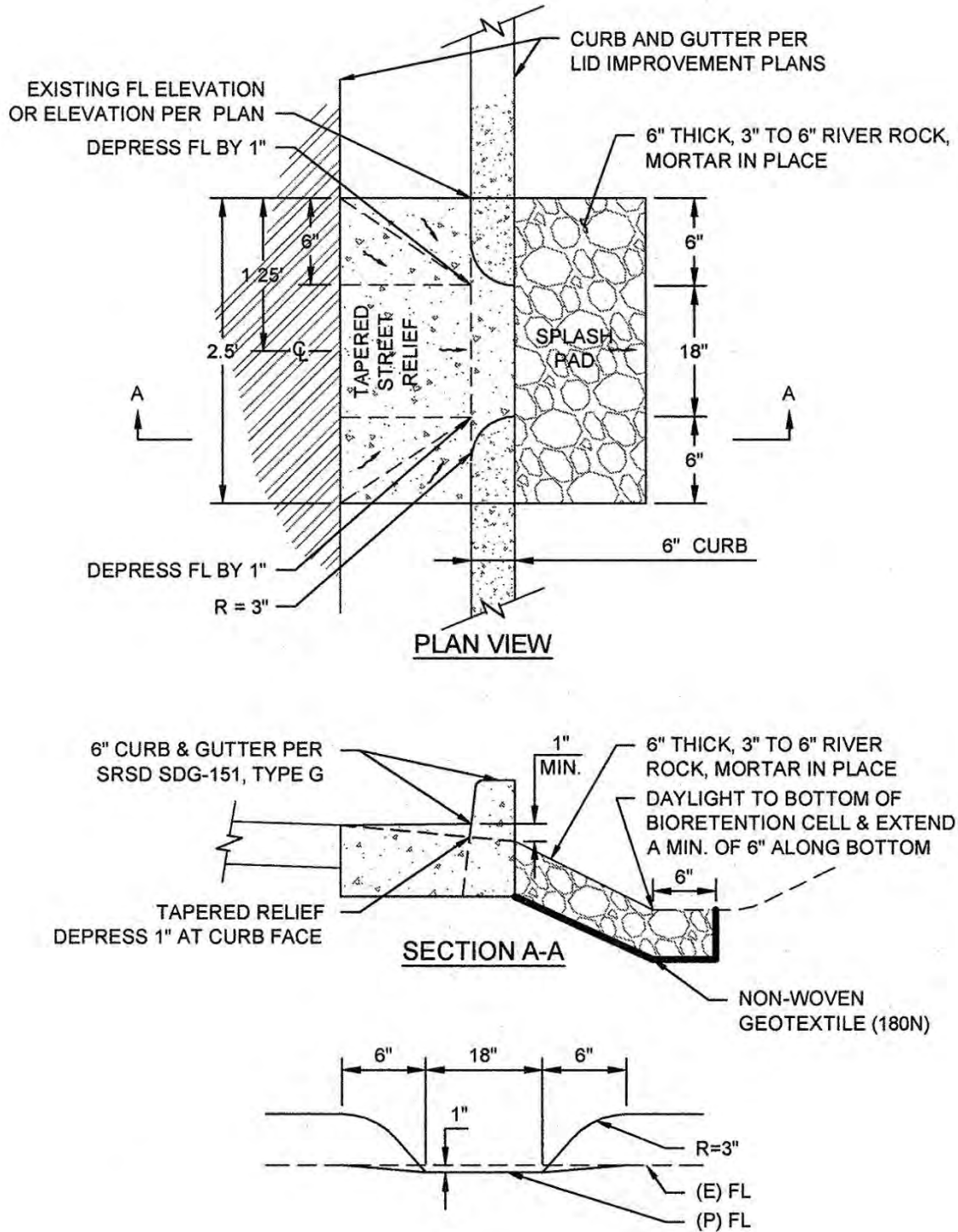


Figure B-13-1. Typical curb cut diagram



Figure B-13-2. A typical curb cut, San Antonio, Texas.

Some pretreatment flow reduction can be provided by using multiple, smaller curb cuts to minimize the flow at each opening and by armoring the curb opening from the back of the curb to the base elevation of the bioretention area (Figure B-13-3).



Figure B-13-3. Multiple, small curb cuts distribute parking lot runoff to bioretention area without erosive force at Mission Library, San Antonio, Texas. Source: Bender Wells Clark Design

Figure B-13-4 and Figure B-13-5 show examples of potential curb cut configurations. Figure B-13-6 shows a covered curb cut that would be appropriate in areas experiencing high levels of pedestrian traffic. Inlets can be covered or protected for pedestrians or other traffic using a covered curb cut. Covered curb cuts, such as the one shown in Figure B-13-6 are preferred over other curb inlet methods including the use of pipes or linear cuts in the curbing for ease of maintenance. Covering the inlet with a removable grate allows for easy visual inspection of the inlet and can reduce the effort required for maintenance. Such curb cuts can also be modified with a small sump or lip to capture coarse sediments and trash. Armoring the curb opening from the back of the curb to the base elevation of the bioretention will reduce inlet velocities, preventing scour and erosion in the BMP.



Figure B-13-4. Curb cuts and vegetated filter strip for a roadside bioretention area, Apex, North Carolina. Source: Tetra Tech



Figure B-13-5. Example curb cut configurations in Raleigh, North Carolina (left) and Downey, California (right). Source: Tetra Tech



Figure B-13-6. Rendering showing a covered curb cut with a sump. Source: City of San Diego LID design Manual

B.13.3 Stabilization and Energy Dissipation

In some cases, the inlet or outlet can be a pipe with concentrated flow. Flow dissipation is difficult yet critical in such situations. Several options can be used for dissipating flow from a pipe. The flow can be discharged into a shallow forebay. Energy dissipation can be implemented at the outlet of the pipe, such as by using sod or stones, to slow the flow as shown in Figure B-13-7. All stone armoring should be sized such that it is not mobilized during high flows and should be underlain with appropriate geotextile fabric to prevent scour of underlying soils. Another option to dissipate energy from small pipes would be to install an elbow at the end of the pipe, with stable materials around the elbow, to slow the flow and allow the water to cascade onto a gravel pad. A small weep hole should be used to prevent water from permanently ponding in the elbow. An example of a constructed energy dissipater is shown in Figure B-13-8, and an upturned elbow used for energy dissipation is shown in Figure B-13-9.



Figure B-13-7. Angular stone flow dissipater/forebay, Cary, North Carolina. Source: Tetra Tech



Figure B-13-8. Concrete energy dissipater, University of Texas at San Antonio, San Antonio, Texas. Source: Tetra Tech



Figure B-13-9. Upturned roof downspout energy dissipater, Chocowinity, North Carolina. Source: Tetra Tech

Level spreaders are another technique for converting concentrated flows into diffuse, sheet flow. Runoff is distributed through a dead-end channel (sometimes called a *blind swale*) along the upslope side of the vegetated filter strip and evenly dispersed onto the vegetated filter strip along the level spreader as shown in Figure B-13-10 and Figure B-13-11. It is important that the lip of the level spreader be accurately level across the entire length and that a minimum 2-inch drop is provided from the lip to the gravel pad below. Level spreaders can be installed in an “arced” configuration if necessary, but the arc should always be convex such that flow is never concentrated (Figure B-13-12). Weir overflow equations can be used to determine the required level spreader length to produce non-erosive flows (Chow 1959).

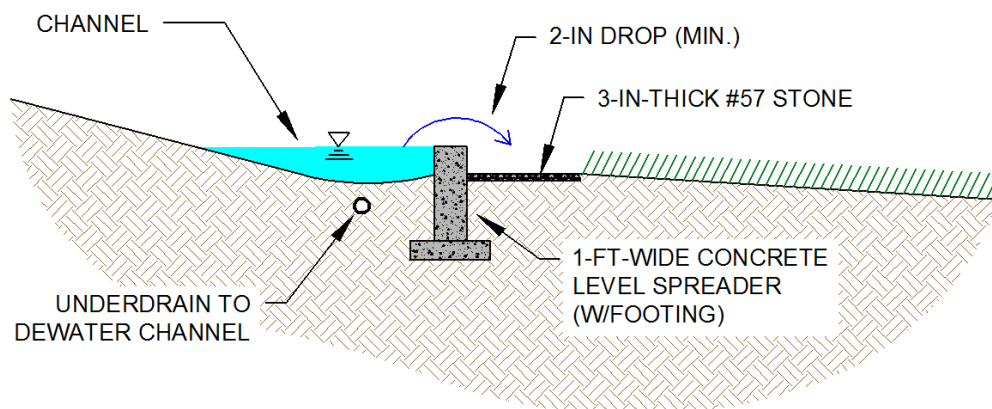


Figure B-13-10. Typical level spreader profile view

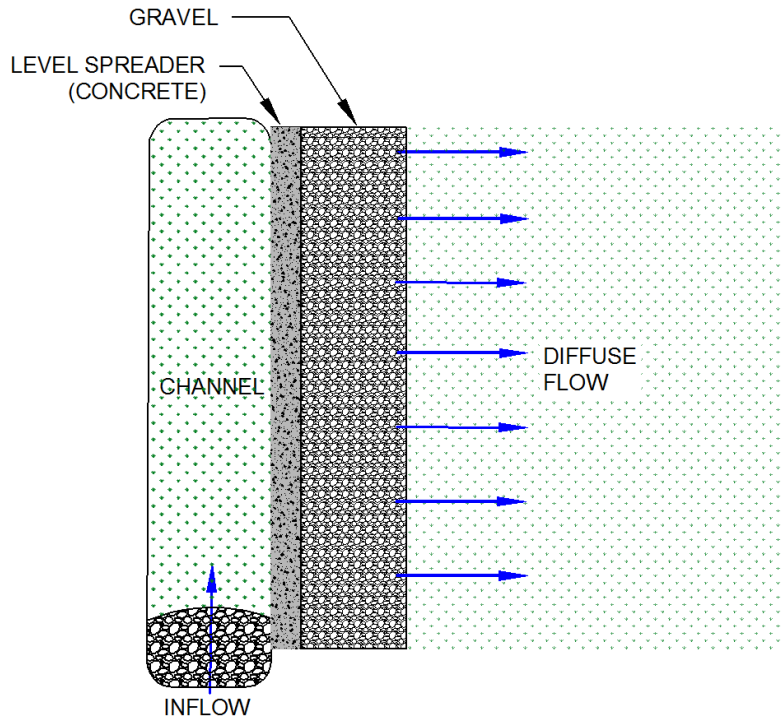


Figure B-13-11. Typical level spreader plan view

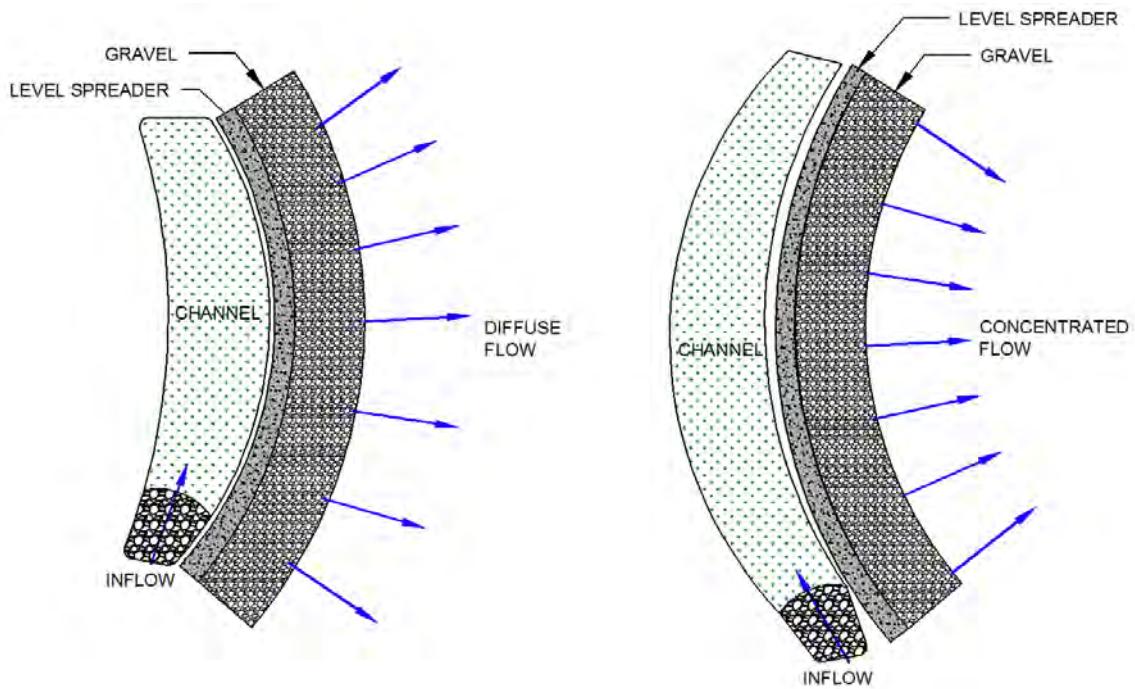


Figure B-13-12. Figure illustrating proper installation of arced level spreader (left) and improper level spreader arc (right)

B.13.4 Underdrain Design

Underdrains are common design elements in bioretention areas, bioswales, planter boxes, and sand filters. Soil testing should be performed at the site by a licensed soil scientist or geological engineer to determine the infiltration rate of the soils and the depth to the seasonally high groundwater table. If the infiltration rate of the soils where the infiltrating practice will be installed is less than 0.5 in/hr, or if a site is near a steep slope, underdrains will be required. If underdrains are used, they should meet the recommended specifications in Table B-13-1.

Table B-13-1. Underdrain specifications (Barrett 2005)

Component	Specification
Diameter	4-inch minimum
Material	Perforated Schedule 40 PVC
Perforation Type	Slotted or round. Slotted underdrains provide greater intake capacity, clog resistant drainage, and reduced entrance velocity into the pipe, thereby reducing the chances of solids migration
Perforation Spacing and Placement	The maximum spacing between perforations should not exceed 6 inches, but spacing of perforations is typically not critical to the function of the BMP as long as the total opening area provides capacity for the expected underdrain flow and does not limit infiltration through the soil media. The perforations can be placed closest to the invert of the pipe to achieve maximum potential for draining the facility. If an anaerobic zone is intended, the perforation can be placed at the top of the pipe.
Slope	1% minimum slope toward outlet
Cleanout Access	Rigid, unperforated observation pipes with a diameter equal to the underdrain diameter should be connected to each individual underdrain (every 250 to 300 feet in larger systems) to provide a cleanout port and an observation well to monitor dewatering rates. The wells/cleanouts should be connected to the perforated underdrain with the appropriate manufactured connections. The wells/cleanouts must extend 6 inches above the mulch or sod layer and be capped with a screw cap to avoid damage from maintenance and vandalism. The ends of upgradient, lateral underdrain pipes not terminating in an observation well/cleanout must also be capped.
Outfall	The underdrain can be connected to a vegetated swale, to another filter cell as part of a connected treatment system, daylight to a vegetated dispersion area using an effective flow dispersion device, stored for reuse, or to a stormwater drainage system.

A barrier to separate the soil media from the drainage layer should be installed. Two options can be used for providing the separation from the soil media and the drainage layer:

- Option 1: Place a thin, 2- to 4-inch layer of pure sand and a thin layer (nominally 2 inches) of choking stone (such as ASTM No. 8) between the soil media and the drainage stone as shown in Figure B-13-13
- Option 2: The drainage stone should be a washed No. 57 stone, or similar alternative that has been washed to remove all fines. The drainage stone should be used to provide a gravel blanket and bedding for the underdrain pipe. Place the underdrain on a 3-foot-wide bed of the drainage stone 6 inches deep and cover with the same drainage stone to provide a 16-inch minimum depth around the bottom, sides, and top of the slotted pipe.

Appendix B.13 Common Design Elements

A geotextile fabric should be placed between the soil media and the drainage layer as shown in Figure B-13-14. If a geotextile fabric is used, it must meet the minimum materials requirements listed in Table B-13-2.

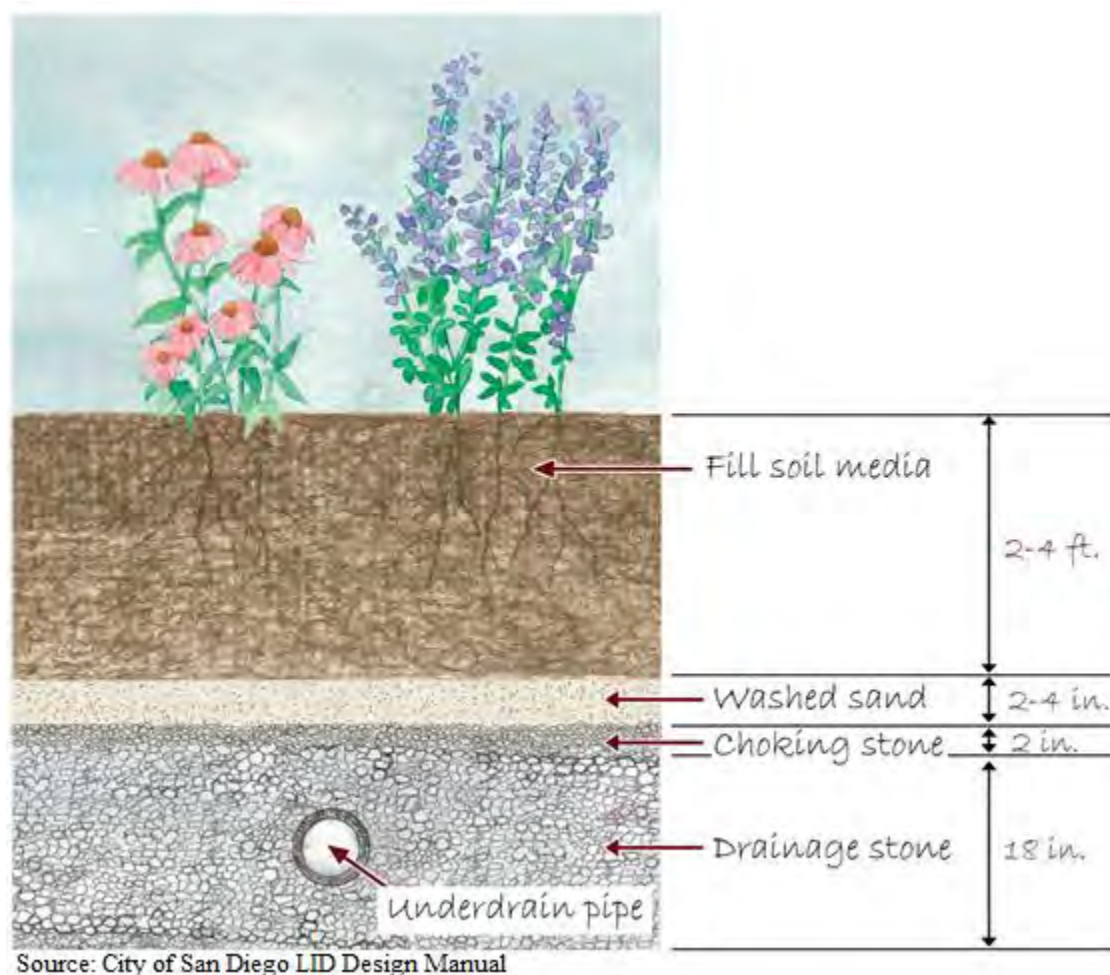


Figure B-13-13. Underdrain barrier option 1: soil media barrier

Table B-13-2. Geotextile layer specifications (Barrett 2005)

Geotextile property	Value	Test method
Trapezoidal tear (lbs)	40 (min)	ASTM D4533
Permeability (cm/sec)	0.2 (min)	ASTM D4491
AOS (sieve size)	#60-#70 (min)	ASTM D4751
Ultraviolet resistance	70% or greater	ASTM D4355

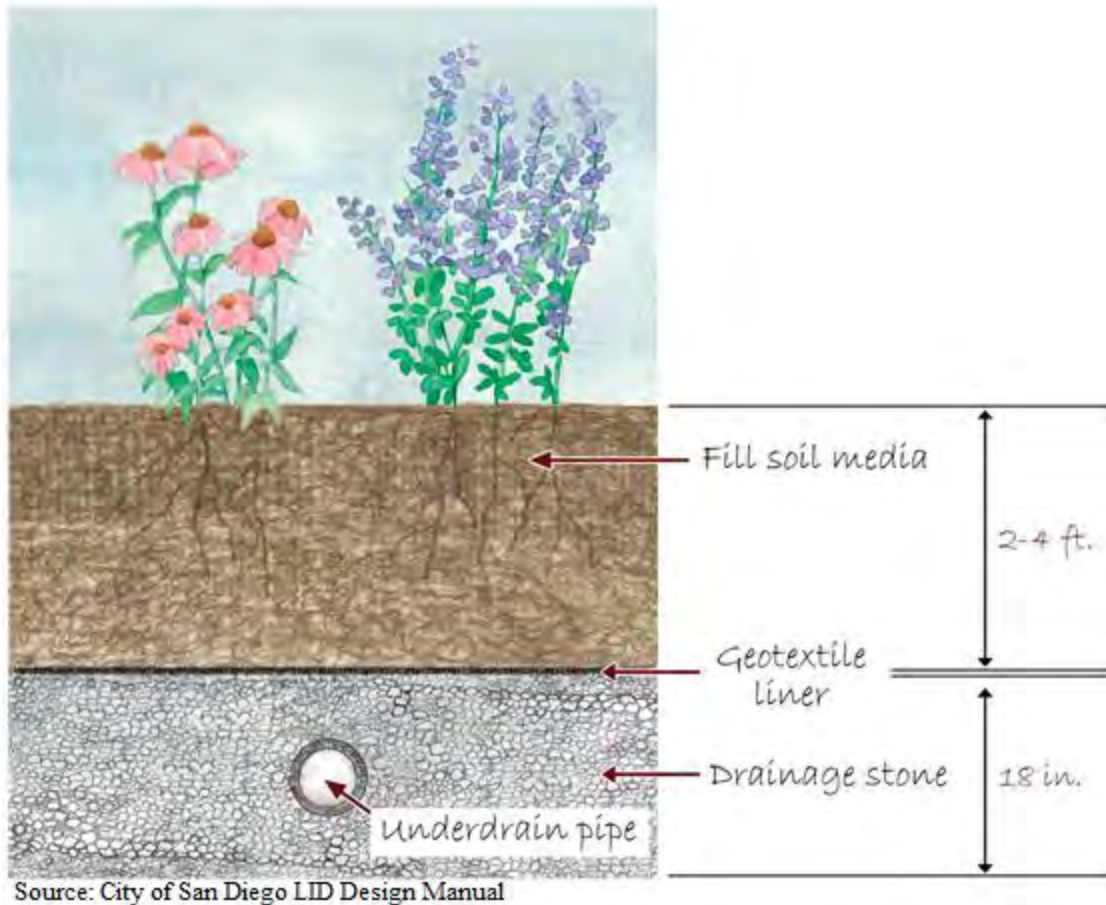


Figure B-13-14. Underdrain barrier option 2: geotextile liner

Option 2 is a common method; however, geotextile clogging and biofouling has been observed in field investigations. In situations where there is concern of clogging around the geotextile, option 1 is recommended.

B.13.5 Trash Bins

Non-clogging intake designs should be specified whenever litter or debris pose a risk of clogging drawdown pipes. For stormwater wetlands, an intake pipe with downturned opening extending 6 to 12 inches below the permanent pool (Figure B-13-15) or enclosing the drawdown orifice (Figure B-13-16) will reduce the risk of clogging by floating debris providing a downward slope on the entire intake pipe can also reduce deposition of sediment within the pipe itself.



Source: NCSU BAE

Figure B-13-15. Drawdown pipe with a downturned elbow



Wilmington, North Carolina. Source: NCSU BAE

Figure B-13-16. Outlet structure with a trash rack and protected downspout orifice

When additional exclusion of trash and debris is required (such as in sand filter sedimentation chambers or for emergency/maintenance dewatering intakes in stormwater wetlands) a trash rack or other debris exclusion device should be specified. A simple trash rack can be designed by nesting a perforated riser pipe within a wire mesh cage. The bottom portion of the pipe should be enveloped in a cone of washed stone (ASTM No. 57 stone is adequate) as shown in Figure B-13-17. The specific trash rack configuration will depend on site conditions and design goals, but regardless of configuration all trash rack should allow for safe bypass of high flows. For further guidance on trash rack design, see Barrett (2005) and UDFCD (2010).

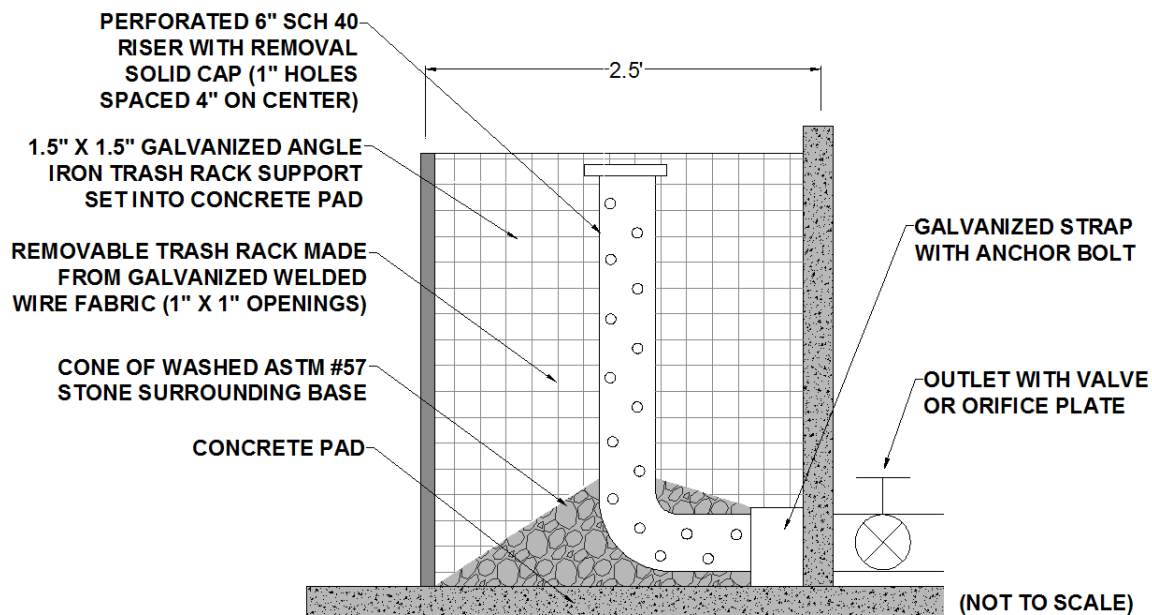


Figure B-13-17. Schematic of a trash rack for dewatering sedimentation chambers and stormwater wetlands (Adapted from Barrett 2005)

B.13.6 Diversion Structures

If a BMP is designed to be an offline system, a structure will be required to divert the design volume into the BMP. Figure B-13-18 shows an example of a typical diversion structure. When the capacity of the BMP is exceeded or the flow exceeds the capacity of the diversion pipe, the flow bypasses over the weir and flows directly to the stormwater drainage system. The bypass pipe should be sized to limit the flow into the BMPs to non-erosive flows. When flows through a BMP could exceed the recommended maximum flow rates, regardless of whether a system is online or offline, a diversion structure is recommended to prevent erosion in the BMP. The flow velocity in a mulched system should not exceed 1 ft/sec. Flow in a grassed system should not exceed 3 ft/sec. Flows can be greater (up to 14 ft/sec) with the use of reinforced turf matting and will depend on the matting selected. A diversion structure should be used to ensure that flows through the system do not exceed the recommended design flow. More information on determining erosive flows can be found in TxDOT (2011).

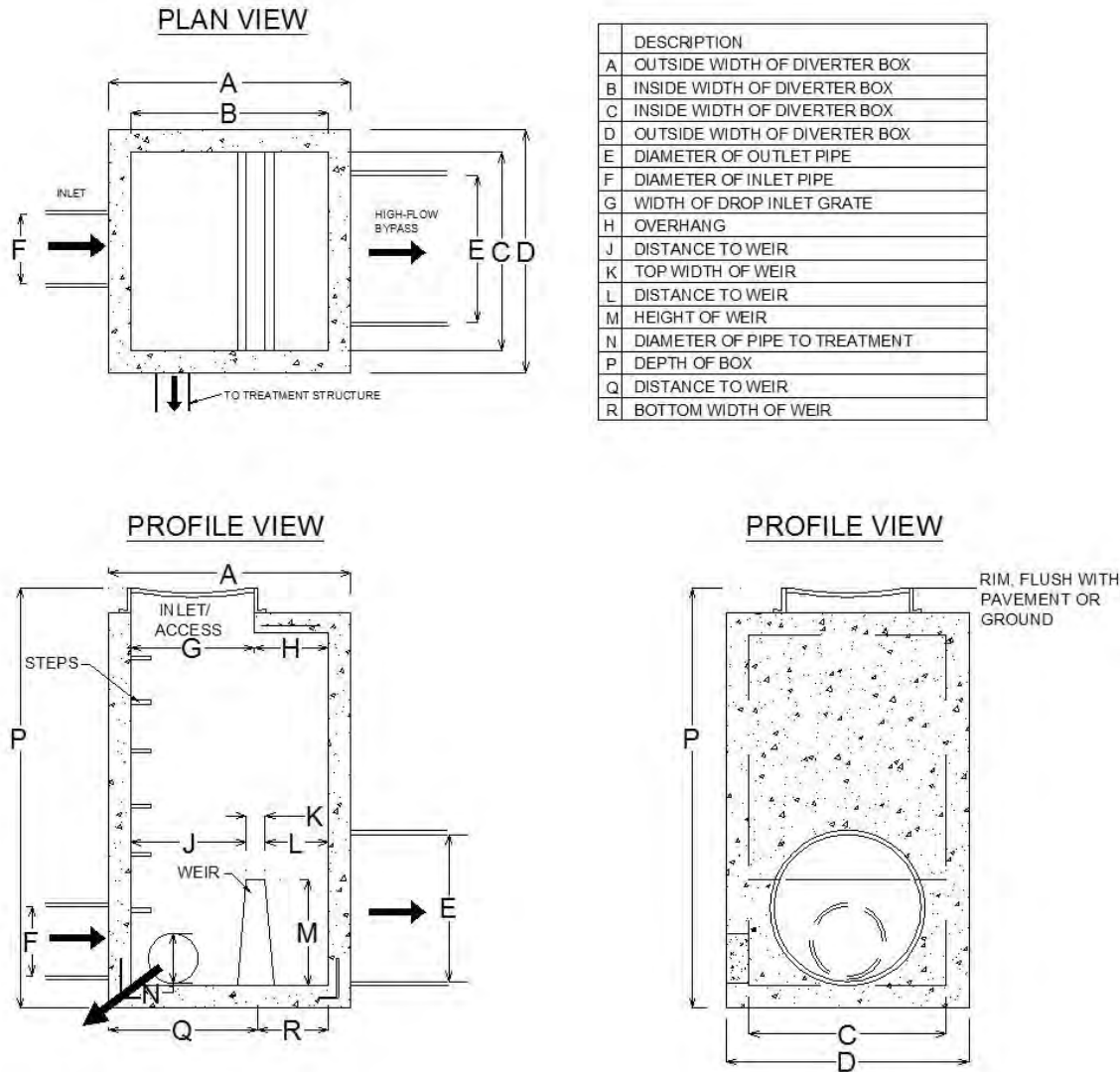


Figure B-13-18. Typical diversion structure

In situations where stormwater is collected in a pipe and routed to a BMP, a diversion structure should be designed at the inlet of the BMP to divert flows that exceed the volume or flow capacity of the BMP.

B.13.7 Impermeable Liners and Hydraulic Restriction Barriers

The most ideal configuration, from a stormwater pollutant-removal perspective, is to infiltrate as much runoff as possible. Types of clay that have a high potential for expansion when saturated should be protected from moisture in load bearing conditions; however, expansive clays do not preclude infiltration. When infiltrating BMPs are hydraulically isolated from structures (by vertical or horizontal distance or by using hydraulic restriction layers), systems installed in tight clays soils can still experience significant volume reductions (Fassman and Blackburn 2010). In situations where conditions require limiting infiltration, two basic options can be used for hydraulic restriction layers.

The preferred option is to restrict lateral flow while allowing for deep percolation infiltration of stormwater. To allow infiltration, the bottom of the bioretention area should remain unlined. The hydraulic restriction layer should extend the full depth of the media to the base of the drainage layer in situations where underdrains are required. In situations where underdrains are not required, the hydraulic restriction layer should extend to a depth where saturation will not affect any adjacent load-bearing soils. Areas that have a potential for settling under saturated conditions should be protected from lateral flows. An example is shown in Figure B-13-19.



Figure B-13-19. Lateral hydraulic restriction layers in a roadside bioretention area prevent horizontal seepage while allowing infiltration at a safe depth

In situations where infiltration is not possible, because of limiting soil capacity or aquifer protection (i.e., Edwards Aquifer Recharge, Contributing, and Transition zones), the entire perimeter of the soil media should be lined to prevent infiltration into the existing soils while gaining some pollutant removal from the soil media. Infiltration pathways might also need to be restricted using impermeable barriers because of the close proximity of roads, foundations, other infrastructure, or hotspot locations as determined in the geotechnical investigation. A full geotechnical investigation should be performed by a licensed soil scientist or geotechnical engineer, as detailed in [Geotechnical Investigation](#). That should be done for all sites to

determine the effect of infiltration, including the appropriate depth and type of the hydraulic restriction layer.

In the Edwards Aquifer Recharge, Transition, and Contributing zones, three types of hydraulic restriction layers are recommended: clay liners, concrete, or geomembranes (Barrett 2005). Specifications for clay liners are provided in Table B-13-3 and an example is shown in Figure B-13-20.

Table B-13-3. Clay liner specifications (Barrett 2005)

Property	Test method	Unit	Specifications
Thickness	--	inch	12
Permeability	ASTM D-2434	cm/sec	1×10^{-6}
Plasticity Index of Clay	ASTM D-423 & D-424	%	Not less than 15
Liquid Limit of Clay	ASTM D-2216	%	Not less than 30
Clay Particles Passing	ASTM D-422	%	Not less than 30
Clay Compaction	ASTM D-2216	%	95% of Standard Proctor Density

If geomembrane is used, it should be a minimum of 30 mils thick and ultraviolet resistant. A suitable geotextile fabric should be placed on both sides (inside and out, top and bottom) of the membrane for puncture protection and the liners covered with a minimum of 6 inches of compacted topsoil. The topsoil should be stabilized with appropriate vegetation. The geotextile fabric (for protection of geomembrane) should be nonwoven geotextile fabric and meet the specifications in Table B-13-4. Construction plans should specify the method for sealing the seams of the geomembrane (per manufacturer recommendations). Seams are typically head sealed by the manufacture but can be sealed in the field following ASTM D7408 standards and all manufacture requirements. An example of a geomembrane liner is shown in Figure B-13-21.

Table B-13-4. Protective geotextile fabric specifications (Barrett 2005)

Property	Test Method	Unit	Specifications
Unit weight	--	oz/yd ²	8
Filtration rate	ASTM D-423 & D-424	0.08	0.08
Puncture strength	ASTM D-751*	lb	125
Mullen burst strength	ASTM D-751	psi	400
Tensile strength	ASTM D-1682	lb	200
Equiv. opening size	US Standard Sieve	No.	80

In addition to geomembranes and clay liners, project sites can use concrete barriers along roadways or other structural features to prevent lateral seepage to adjacent utilities or areas of concern (as shown in Figure B-13-22). Concrete barriers can be constructed as extensions of the surrounding curb installed vertically to the depth where saturation will not affect the stability of the load-bearing soils. Concrete barriers will prevent damage that can occur from maintenance required for utilities in the right-of-way.



Figure B-13-20. Bioretention area with clay liner and lateral hydraulic restriction barriers



Figure B-13-21. Bioretention area with geomembrane layer



Figure B-13-22. Bioretention area completely lined with concrete barrier (planter box)

B.13.8 Utilities

When implementing BMPs, avoid utilities where possible. In many cases, the BMP can be shifted in the landscape to prevent implementation over utilities. In cases where utilities cannot be avoided, take care to prevent effects from infiltration or saturation by using hydraulic restricting layers to direct infiltration away from the utility. The utility should pass through the hydraulic restriction layer, and the liner should be appropriately sealed to prevent any lateral seepage from the BMP. Liners can be easily sealed by using a patch that adheres to the utility line and sealed directly to the liner. Local plumbing codes should be reviewed for restrictions pertaining to water and sewer utilities.

The location of future utilities should also be considered in the site layout and location of BMPs. Long, linear BMPs, such as a bioretention area or bioswale in the right-of-way, should have periodic breaks to allow for future utility trenches. At least one access point should be placed along any BMP for each parcel where there is a separation or break in the liner for a utility trench. BMPs in such a scenario should be designed as separate systems with separate hydraulic restriction layers, but they could be connected at the subsurface through the underdrain or at the surface by a trench with a grate similar to a covered curb cut. For more details, see Connectivity below.

B.13.9 Connectivity

When BMPs are implemented in the right-of-way and parking lots, it is important to maintain pedestrian access routes to prevent disturbance to the BMP, prevent harm to the public, and provide connections for future utilities. It is also important that sections of the BMP remain hydraulically connected to fully use as much of the BMP as possible. BMPs should be connected by open channels covered with an appropriate grate to allow visual inspection of the channel and ease of maintenance. Culverts can be used for larger facilities, but they should be inspected regularly for blockages. Figure B-13-23 shows pedestrian access over BMPs while maintaining appropriate hydraulic connectivity.



San Antonio, Texas. Source: SARA



San Antonio, Texas, Source: SARA.



Raleigh, North Carolina. Source: Tetra Tech, Inc.

Figure B-13-23. Access over linear BMPs

B.13.10 ADA Requirements

BMPs typically require surfaces with little to no slope, therefore, Americans with Disabilities Act (ADA) requirements are rarely an issue. However, in areas with high levels of pedestrian traffic, some effort should be made to delineate the BMP. Several options—including low-level and decorative fencing, such as the one shown in Figure B-13-24, or a low-profile curb, as shown in Figure B-13-25, can often be used to delineate the space around the BMP and alert pedestrians of the change in grade.



San Antonio, Texas. Source: SARA

Figure B-13-24. Low-level fencing



Greensboro, North Carolina. Source: Tetra Tech

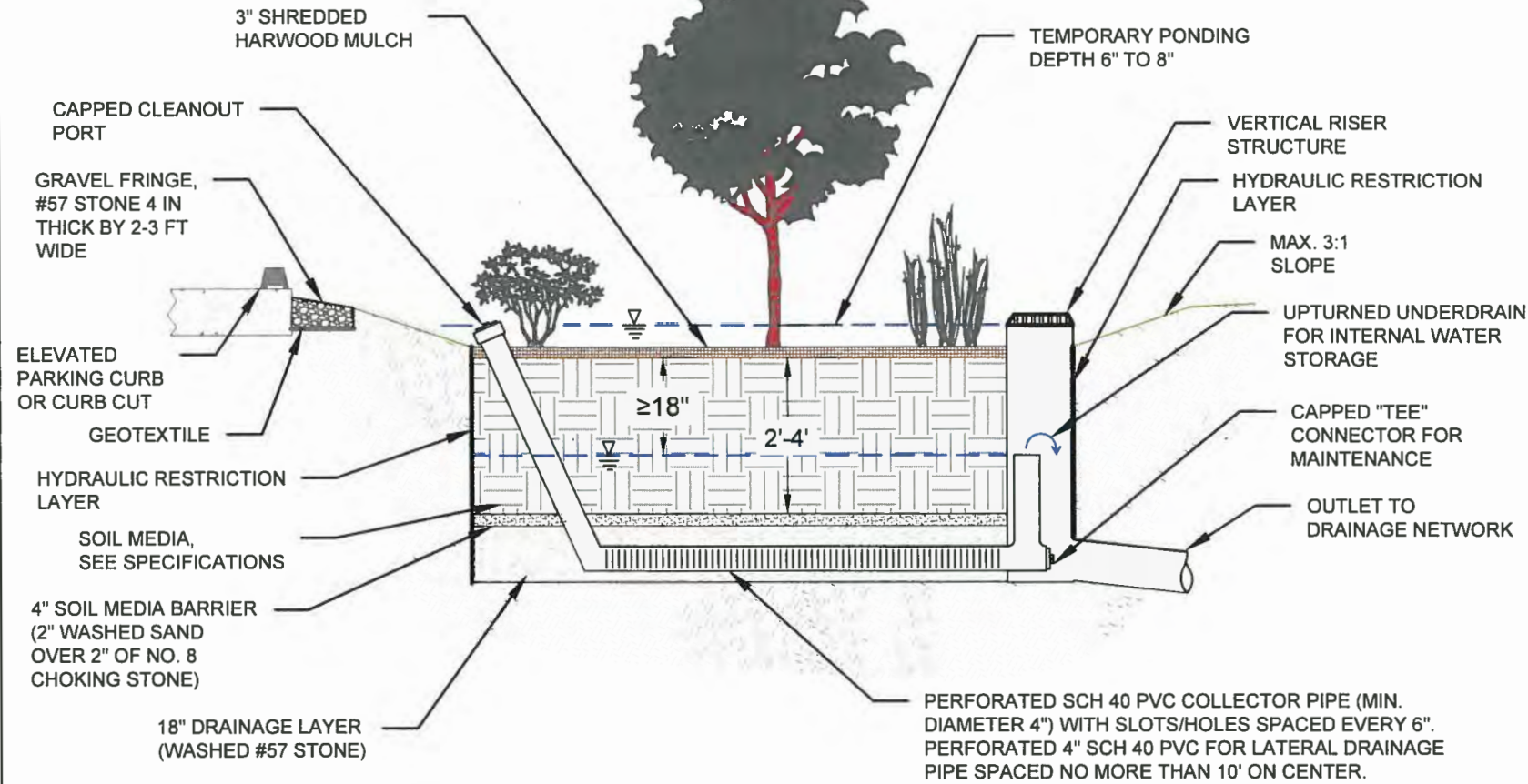
Figure B-13-25. Low-profile curbing

B.13.11 References

- Barrett, M.E. 2005. *Complying with the Edwards Aquifer Rules. Technical Guidance on Best Management Practices*. RG-348. Prepared for Texas Commission on Environmental Quality, Field Operations Division, Austin, TX.
- Fassman, E.A. and S. Blackbourn. 2010. Urban runoff mitigation by a permeable pavement system over impermeable soils. *Journal of Hydrologic Engineering* 15(6):475-485.
- TxDOT (Texas Department of Transportation). 2011. Chapter 13, Section 2. Soil Erosion Control Considerations. *Hydraulic Design Manual*. Austin, TX.
- UDFCD (Urban Drainage and Flood Control District). 2010. T-12 Outlet Structures. Urban Storm Drainage Criteria Manual, Volume 3 – Best Management Practices. Denver, CO.
http://www.udfcd.org/downloads/down_critmanual_volIII.htm.

Appendix C. BMP Design Templates

NOTE: IF NO IMPERMEABLE LINER IS REQUIRED, ENSURE THAT SUBGRADE COMPACTION IS MINIMIZED DURING CONSTRUCTION. SCARIFY OR RIP SUBGRADE TO A DEPTH OF 9-12".



PROFILE W/ INTERNAL WATER STORAGE PROFILE (TYP.)

NTS

SOIL MEDIA SPECIFICATIONS

TEXTURE AND COMPOSITION (BY VOLUME)

SOIL MEDIA SHOULD CONSIST OF A LOAMY SAND CONFORMING TO THE FOLLOWING SPECIFICATIONS

- 85-88% WASHED COARSE SAND (CONCRETE SAND PASSING A 1/2" SIEVE OR THOROUGHLY WASHED MORTAR SAND PASSING A 3/8" SIEVE)
- 8-12% FINES PASSING A #270 SIEVE
- 2-5% ORGANIC MATTER

ORGANIC MATTER MATERIAL

AGED BARK FINES, HARDWOOD CHIPS, OR SIMILAR PLANT-DERIVED ORGANIC MATERIAL. ORGANIC MATTER SHOULD INCLUDE NO ANIMAL MANURE OR BYPRODUCTS

INFILTRATION RATES

0.5 TO 6 IN/HR (1-2 IN/HR RECOMMENDED FOR COMPREHENSIVE POLLUTANT TREATMENT AND HYDROLOGIC BENEFIT)

PH

6 TO 8

CATION EXCHANGE CAPACITY (CEC)

GREATER THAN 5 MILLIEQUIVALENTS (MEQ)/100 G SOIL

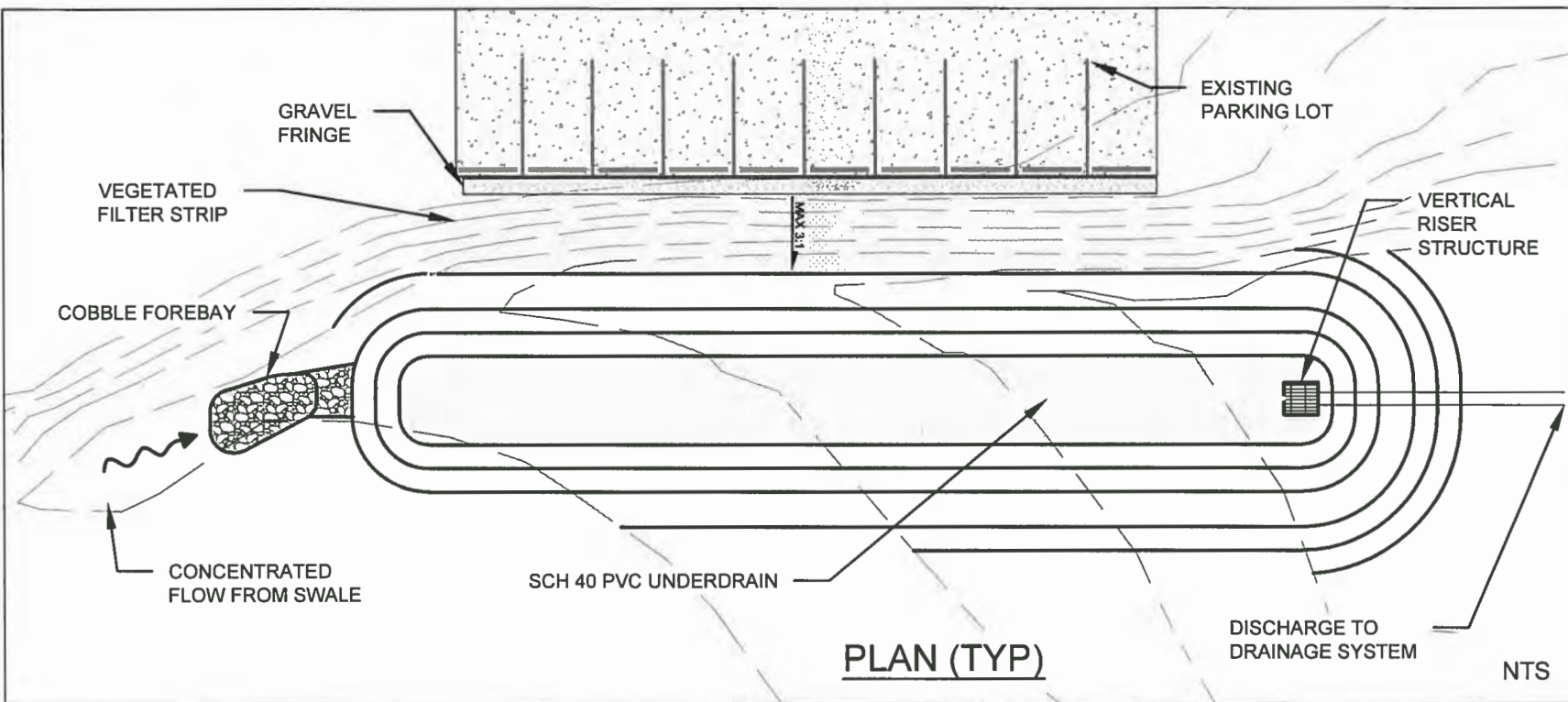
PHOSPHORUS

TOTAL PHOSPHORUS SHOULD NOT EXCEED 15 PPM

VEGETATION SPECIFICATIONS

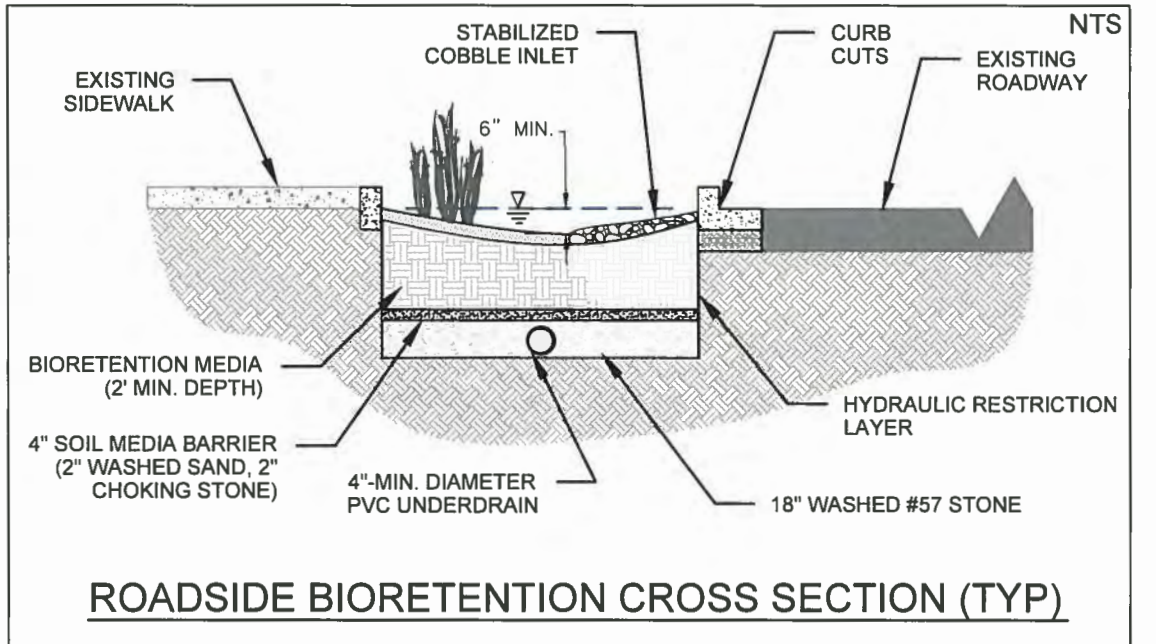
FOR BIOSWALES TO FUNCTION PROPERLY AS STORMWATER TREATMENT AND BLEND INTO THE LANDSCAPING, VEGETATION SELECTION IS CRUCIAL. APPROPRIATE VEGETATION WILL HAVE THE FOLLOWING CHARACTERISTICS

1. PLANT MATERIALS MUST BE TOLERANT OF SUMMER DROUGHT, PONDING FLUCTUATIONS, AND SATURATED SOIL CONDITIONS FOR 10 TO 48 HOURS
2. IT IS RECOMMENDED THAT A MINIMUM OF THREE TREE, THREE SHRUBS, AND THREE HERBACEOUS GROUNDCOVER SPECIES BE INCORPORATED TO PROTECT AGAINST FACILITY FAILURE FROM DISEASE AND INSECT INFESTATIONS OF A SINGLE SPECIES. PLANT ROOTING DEPTHS MUST NOT DAMAGE THE UNDERDRAIN. IF PRESENT, SLOTTED OR PERFORATED UNDERDRAIN PIPE MUST BE MORE THAN 5 FEET FROM TREE LOCATIONS (IF SPACE ALLOWS)
3. NATIVE PLANT SPECIES THAT ARE NOT INVASIVE AND DO NOT REQUIRE CHEMICAL INPUTS ARE RECOMMENDED TO BE USED TO THE MAXIMUM EXTENT PRACTICABLE
4. SHADE TREES SHOULD BE FREE OF BRANCHES FOR THE BOTTOM 1/3 OF THEIR TOTAL HEIGHT AND LINES OF SITE SHOULD BE MAINTAINED WITH PLANTING ALONG THE TRANSPORTATION CORRIDOR



PLAN (TYP.)

NTS



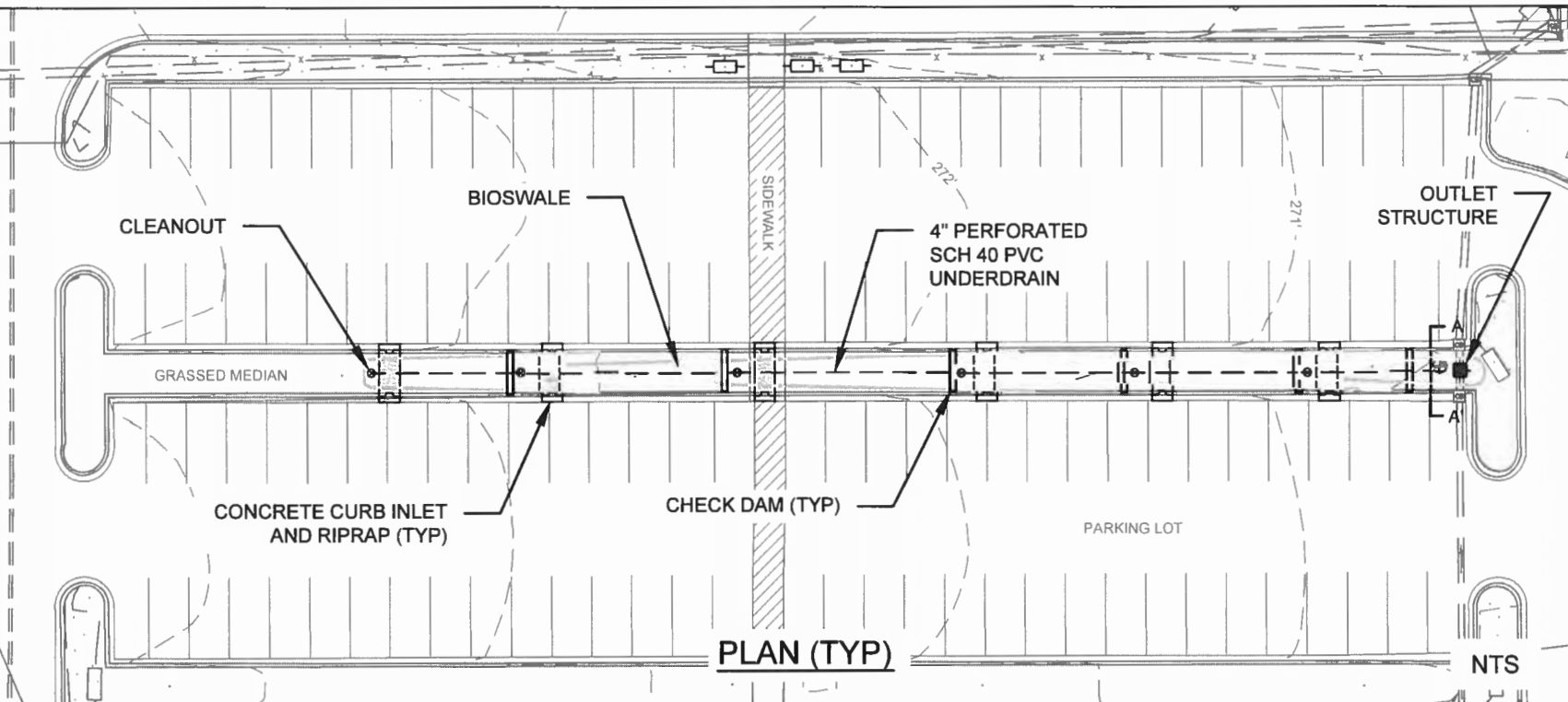
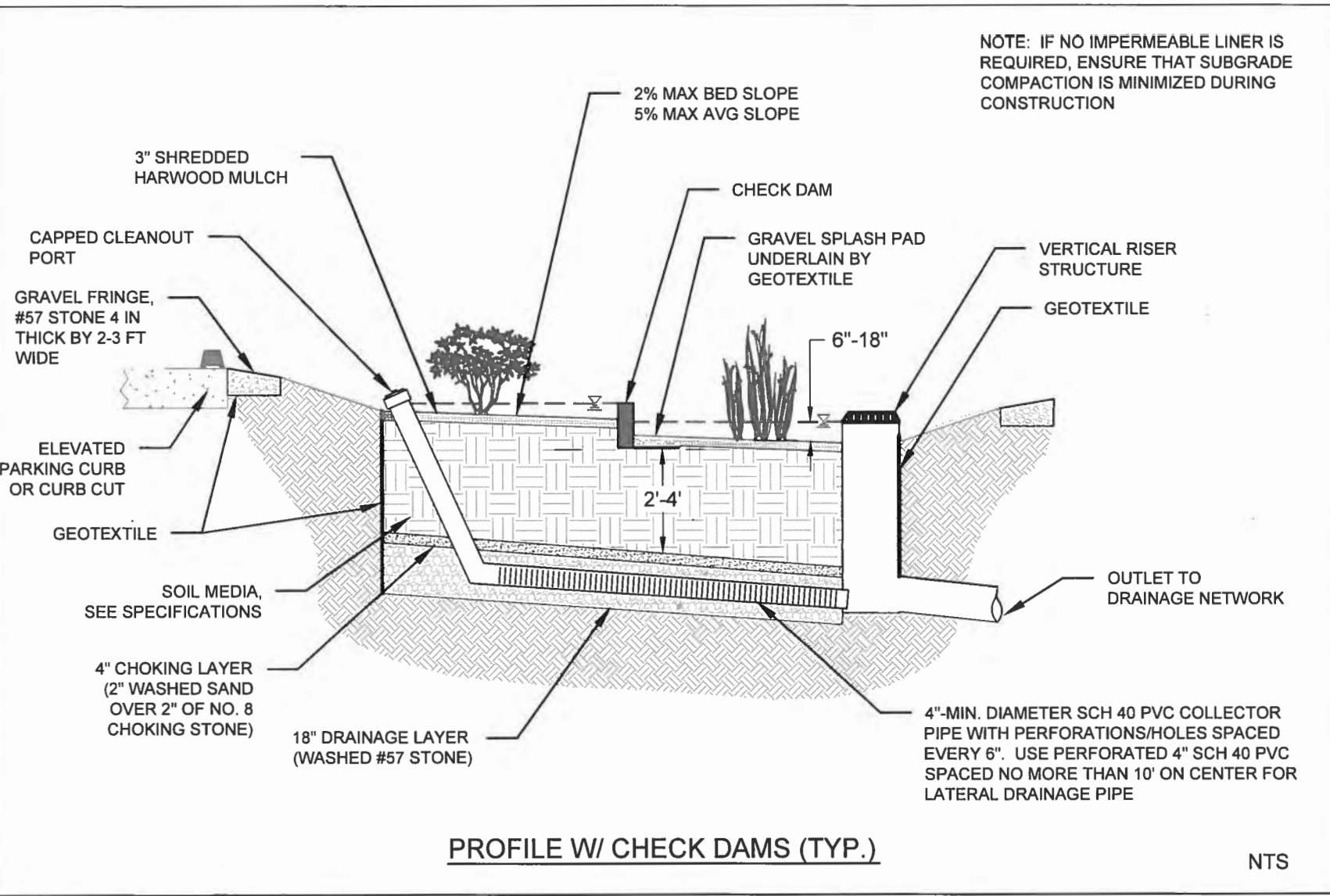
ROADSIDE BIORETENTION CROSS SECTION (TYP.)

CONSULTANT NAME
STREET NUMBER AND ADDRESS

SAN ANTONIO RIVER AUTHORITY
CAPITAL IMPROVEMENTS MANAGEMENT SERVICES DEPARTMENT

BIORETENTION

DATE: _____	PROJECT NO.: _____	% SUBMITTAL: _____
SHEET NO.: _____ OF _____	CHKD. BY: _____	DRWN BY: _____



SOIL MEDIA SPECIFICATIONS

TEXTURE AND COMPOSITION (BY VOLUME):
SOIL MEDIA SHOULD CONSIST OF A LOAMY SAND CONFORMING TO THE FOLLOWING SPECIFICATIONS:

- 85-88% WASHED COARSE SAND (CONCRETE SAND PASSING A 1/2" SIEVE OR THOROUGHLY WASHED MORTAR SAND PASSING A 1/2" SIEVE)
- 8-12% FINES PASSING A #270 SIEVE
- 2-5% ORGANIC MATTER

ORGANIC MATTER MATERIAL:
AGED BARK FINES, HARDWOOD CHIPS, OR SIMILAR PLANT-DERIVED ORGANIC MATERIAL. ORGANIC MATTER SHOULD INCLUDE NO ANIMAL MANURE OR BYPRODUCTS.

INFILTRATION RATES:
1.5 TO 6 IN/HR (1-2 IN/HR RECOMMENDED FOR COMPREHENSIVE POLLUTANT TREATMENT AND HYDROLOGIC BENEFIT)

PH:
6 TO 8

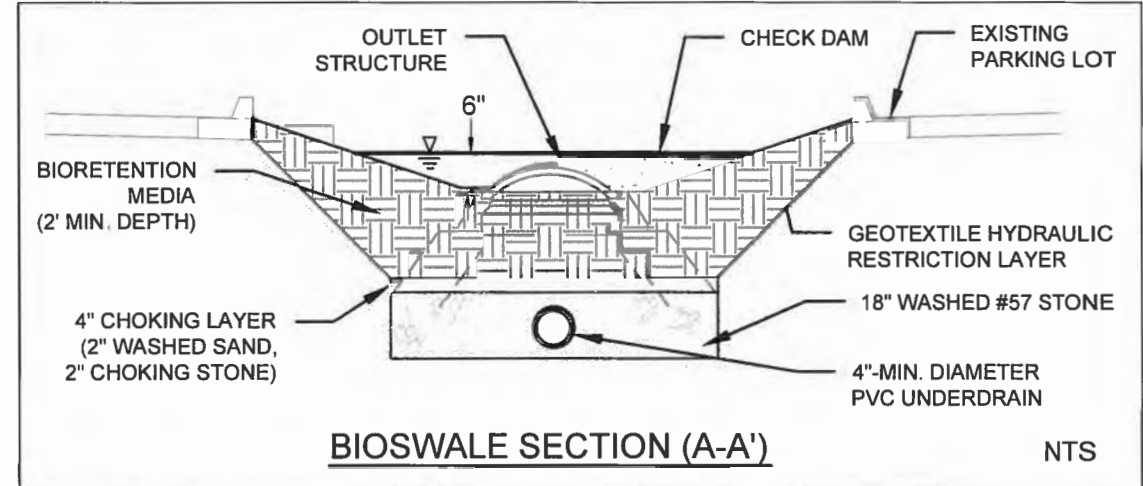
CATION EXCHANGE CAPACITY (CEC):
GREATER THAN 5 MILLIEQUIVALENTS (MEQ)/100 G SOIL

PHOSPHORUS:
TOTAL PHOSPHORUS SHOULD NOT EXCEED 15 PPM

VEGETATION SPECIFICATIONS

FOR BIOSWALES TO FUNCTION PROPERLY AS STORMWATER TREATMENT AND BLEND INTO THE LANDSCAPING, VEGETATION SELECTION IS CRUCIAL. APPROPRIATE VEGETATION WILL HAVE THE FOLLOWING CHARACTERISTICS:

1. PLANT MATERIALS MUST BE TOLERANT OF SUMMER DROUGHT, FLOODING FLUCTUATIONS, AND SATURATED SOIL CONDITIONS FOR 10 TO 48 HOURS.
2. IT IS RECOMMENDED THAT A MINIMUM OF THREE TREE, THREE SHRUBS, AND THREE HERBACEOUS GRASS/COVER SPECIES BE INCORPORATED TO PROTECT AGAINST FACILITY FAILURE FROM DISEASE AND INSECT INFESTATIONS OF A SINGLE SPECIES. PLANT ROOTING DEPTHS MUST NOT DAMAGE THE UNDERDRAIN, IF PRESENT. SLOTTED OR PERFORATED UNDERDRAIN PIPE MUST BE MORE THAN 5 FEET FROM TREE LOCATIONS (IF SPACE ALLOWS).
3. NATIVE PLANT SPECIES THAT ARE NOT INVASIVE AND DO NOT REQUIRE CHEMICAL INPUTS ARE RECOMMENDED TO BE USED TO THE MAXIMUM EXTENT PRACTICABLE.
4. SHADE TREES SHOULD BE FREE OF BRANCHES FOR THE BOTTOM 1/3 OF THEIR TOTAL HEIGHT AND LINES OF SITE SHOULD BE MAINTAINED WHEN PLANTING ALONG TRANSPORTATION CORRIDORS.



CONSULTANT NAME
STREET NUMBER AND ADDRESS

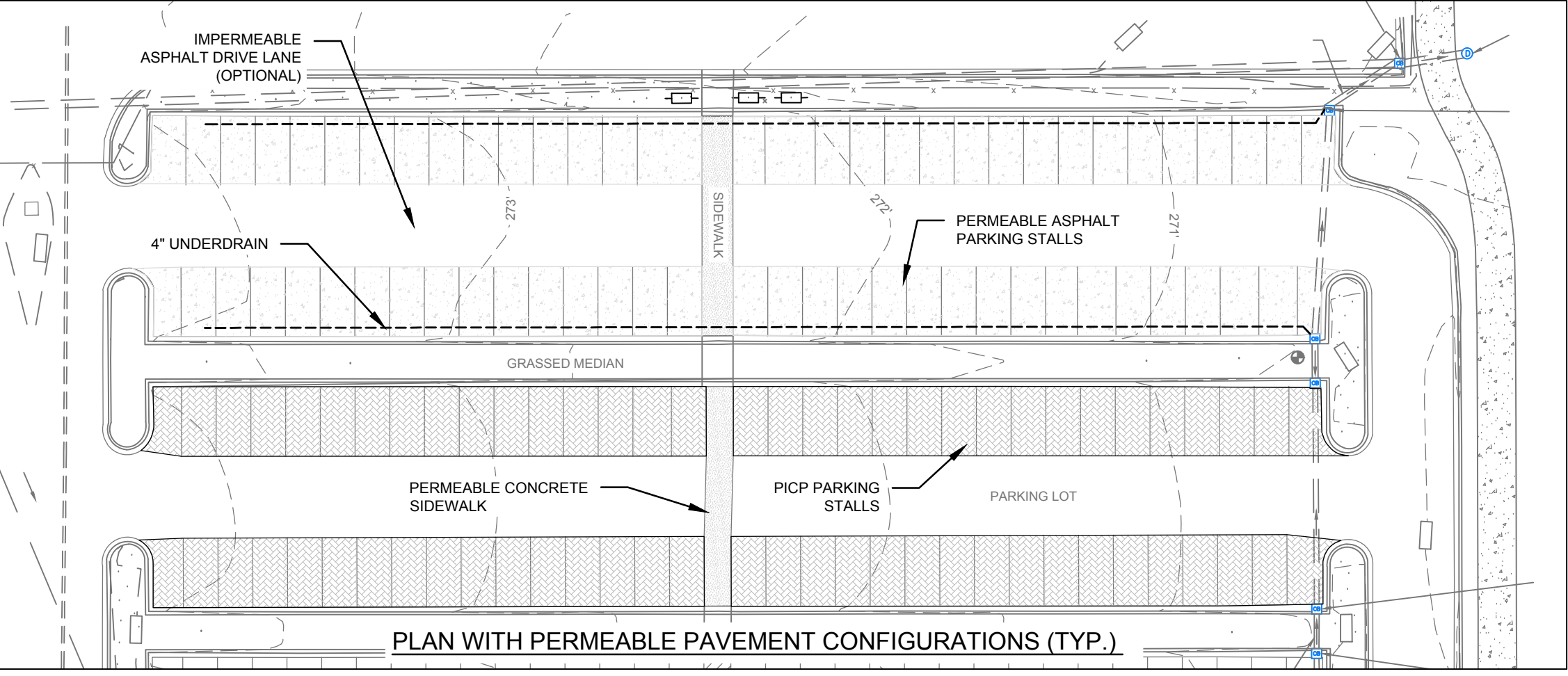
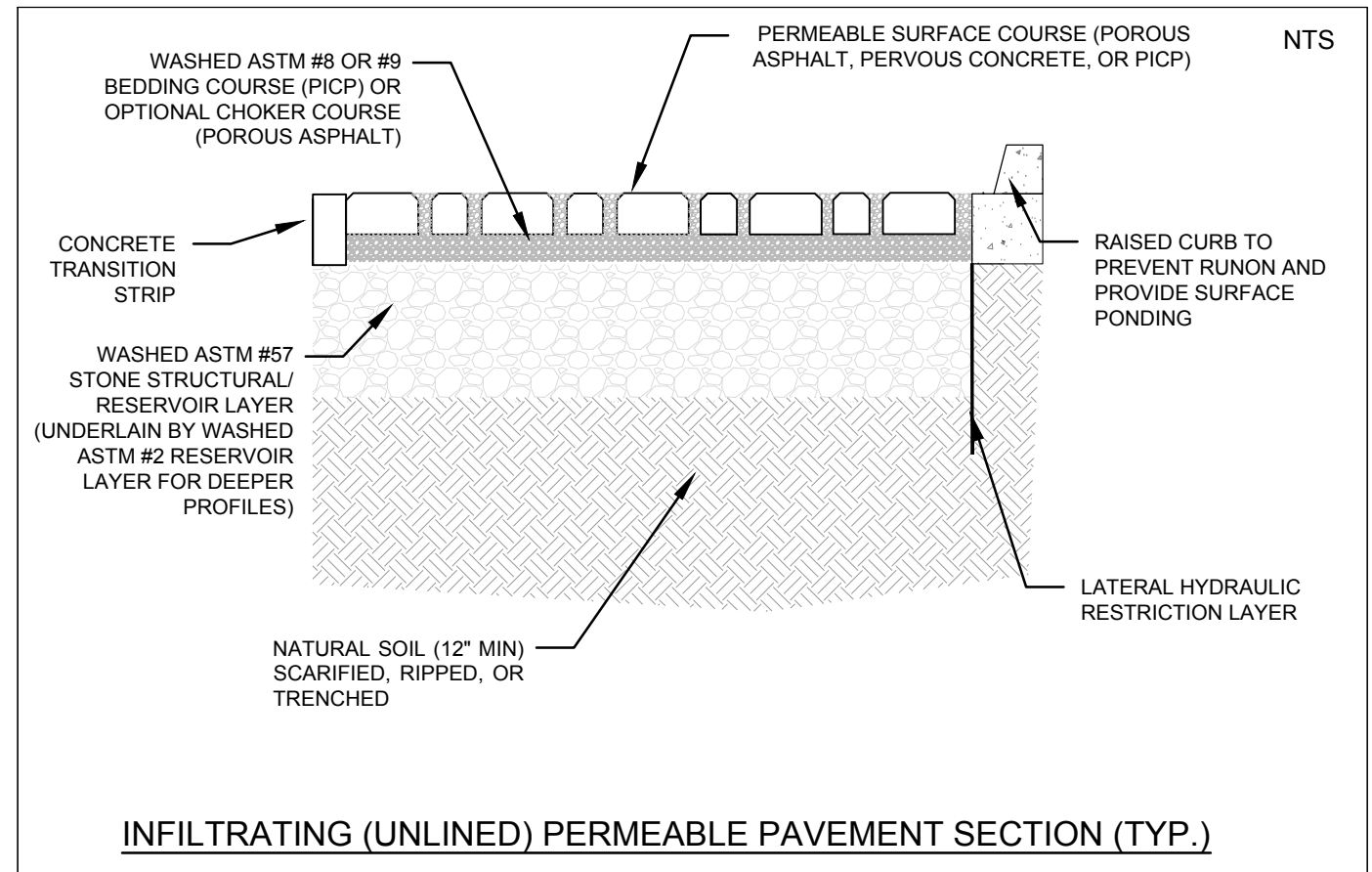
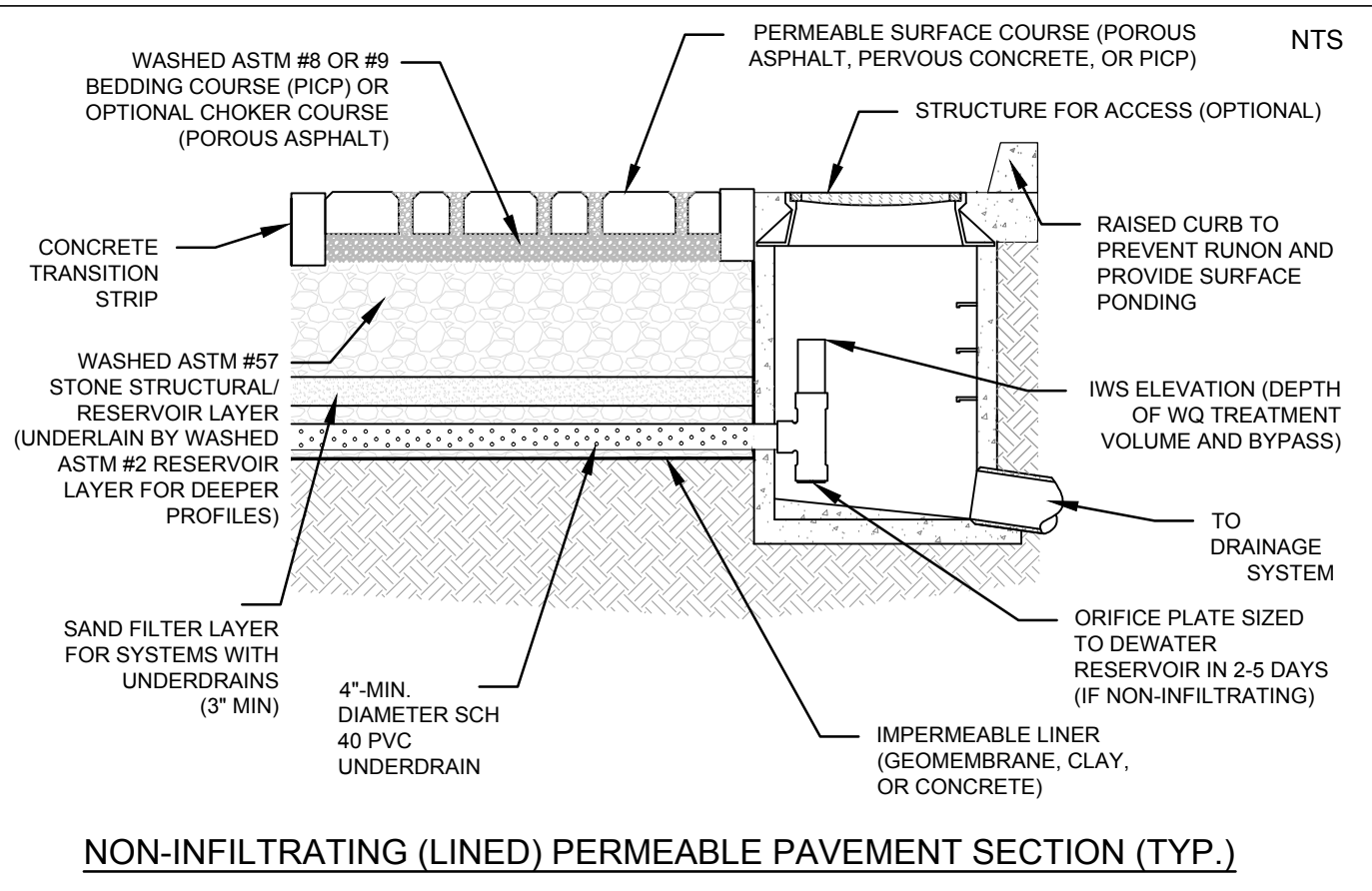
SAN ANTONIO RIVER AUTHORITY
CAPITAL IMPROVEMENTS MANAGEMENT SERVICES DEPARTMENT

BIOSWALE

DATE: _____

PROJECT NO.: _____

DRWN. BY: _____ DSGN. BY: _____ CHKD. BY: _____ SHEET NO.: _____ OF _____

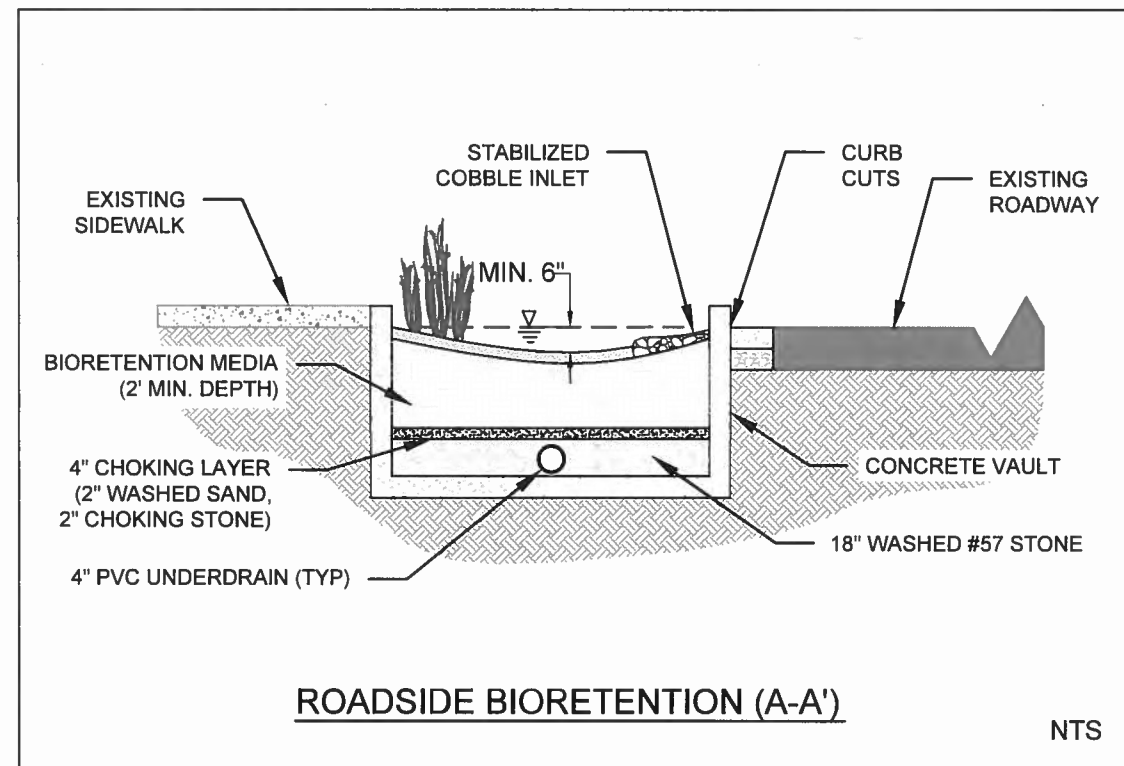
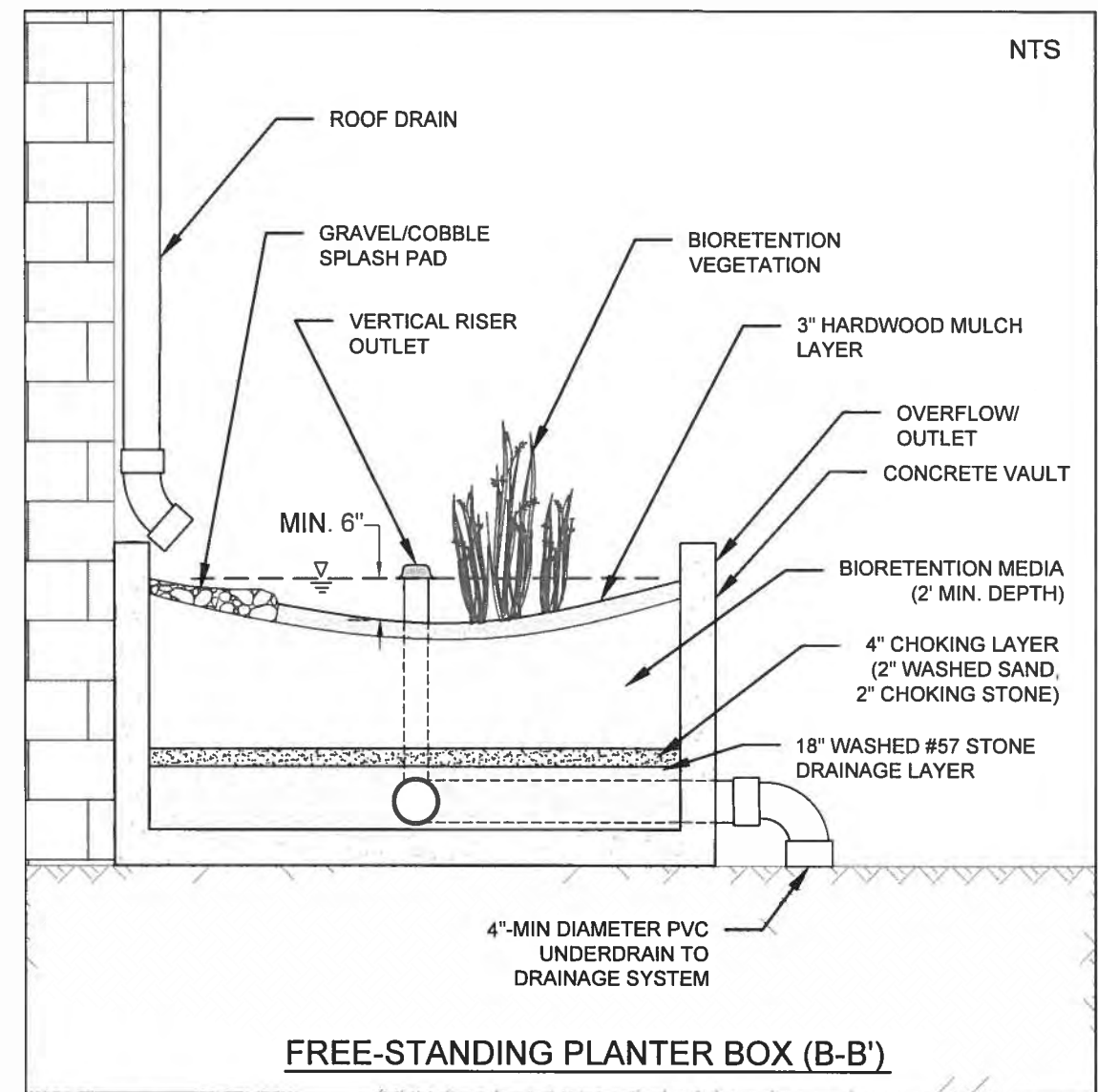
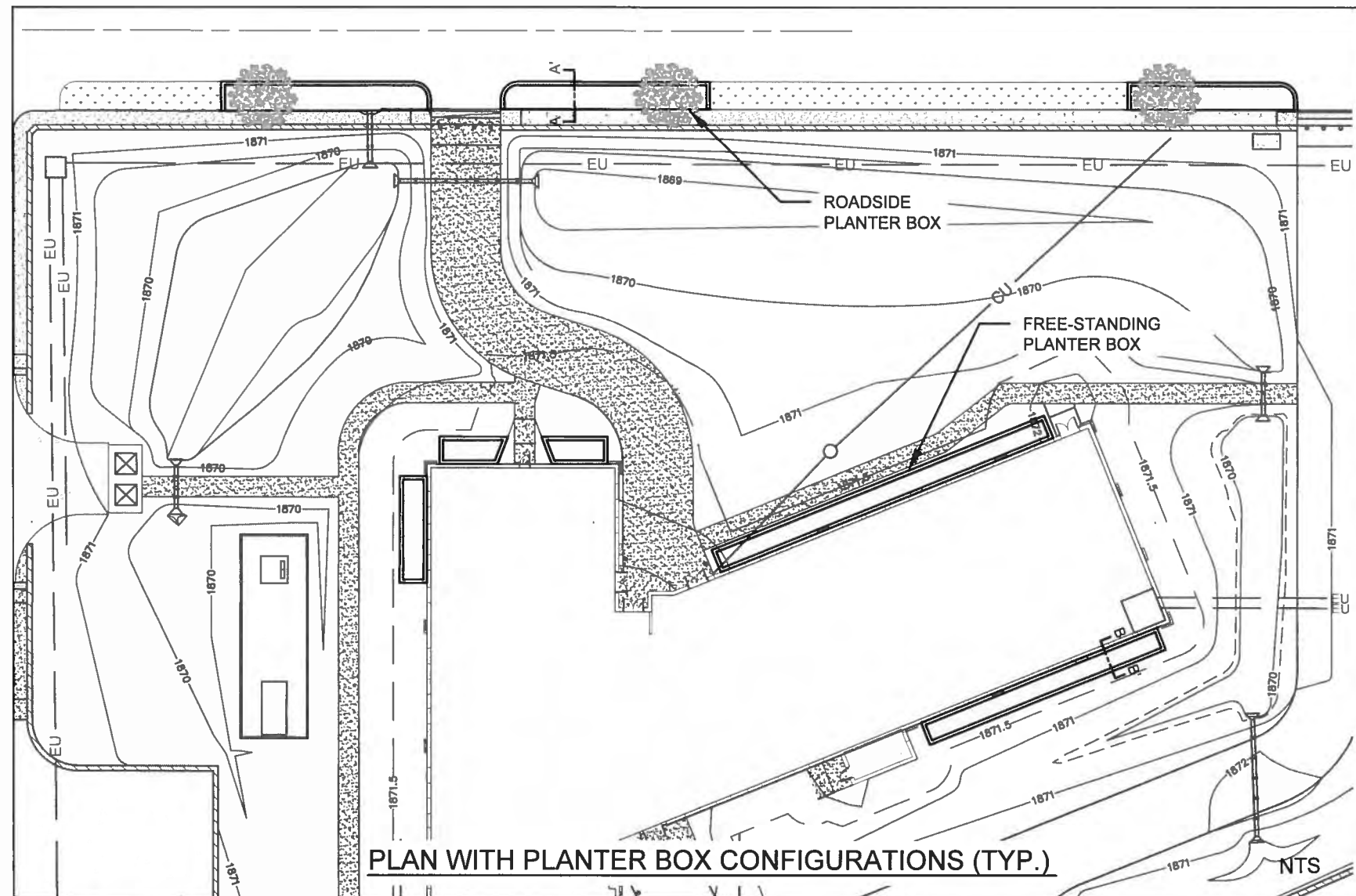


- NOTES:**
1. ALL AGGREGATE SHOULD BE WASHED, ANGULAR, CRUSHED STONE.
 2. OBSERVATION WELLS SHOULD BE CONSTRUCTED OF PERFORATED 4" SCH 40 AND CAPPED TO PREVENT INJURY OR VEHICULAR DAMAGE.
 3. SUBGRADE SLOPES SHOULD NOT EXCEED 0.5% WITHOUT ANALYSIS BY A STRUCTURAL ENGINEER. BAFFLES SHOULD BE INSTALLED IN SLOPED SYSTEMS TO RETAIN THE DESIGN VOLUME.
 4. SYSTEMS WITH PICP SHOULD PROVIDE INTERNAL BYPASS FOR HIGH FLOWS TO PREVENT UPLIFT AND TRANSPORT OF BEDDING COURSE. PERVIOUS CONCRETE AND POROUS ASPHALT MAY BYPASS ON THE SURFACE.

GEOTEXTILE SPECIFICATIONS:
(FOR PROTECTION OF GEOMEMBRANES)

Geotextile property	Value	Test method
Grab tensile strength (lbs)	≥ 120	ASTM D4632
Mullen burst strength (lbs/sq. in.)	≥ 225	ASTM D3786
Permeability (gpm/sq. ft.)	≥ 125	ASTM D4491
Apparent opening size (sieve size)	#70-#80 (min)	ASTM D4751

CONSULTANT NAME STREET NUMBER AND ADDRESS		
SAN ANTONIO RIVER AUTHORITY CAPITAL IMPROVEMENTS MANAGEMENT SERVICES DEPARTMENT		
PERMEABLE PAVEMENT		
DATE:	PROJECT NO.:	% SUBMITTAL
DRWN. BY:	DSGN. BY:	CHKD. BY:
SHEET NO.:	OF	



SOIL MEDIA SPECIFICATIONS

TEXTURE AND COMPOSITION (BY VOLUME):

SOIL MEDIA SHOULD CONSIST OF A LOAMY SAND CONFORMING TO THE FOLLOWING SPECIFICATIONS:

- 85-88% WASHED COARSE SAND (CONCRETE SAND PASSING A 1/4" SIEVE OR THOROUGHLY WASHED MORTAR SAND PASSING A 1/8" SIEVE)
- 8-12% FINES PASSING A #270 SIEVE
- 2-5% ORGANIC MATTER

ORGANIC MATTER MATERIAL:

AGED BARK FINES, HARDWOOD CHIPS, OR SIMILAR PLANT-DERIVED ORGANIC MATERIAL. ORGANIC MATTER SHOULD INCLUDE NO ANIMAL MANURE OR BYPRODUCTS.

INFILTRATION RATES:

0.5 TO 6 IN/HR (1-2 IN/HR RECOMMENDED FOR COMPREHENSIVE POLLUTANT TREATMENT AND HYDROLOGIC BENEFIT)

PH:

6 TO 8

CATION EXCHANGE CAPACITY (CEC):

GREATER THAN 5 MILLIEQUIVALENTS (MEQ)/100 G SOIL

PHOSPHORUS:

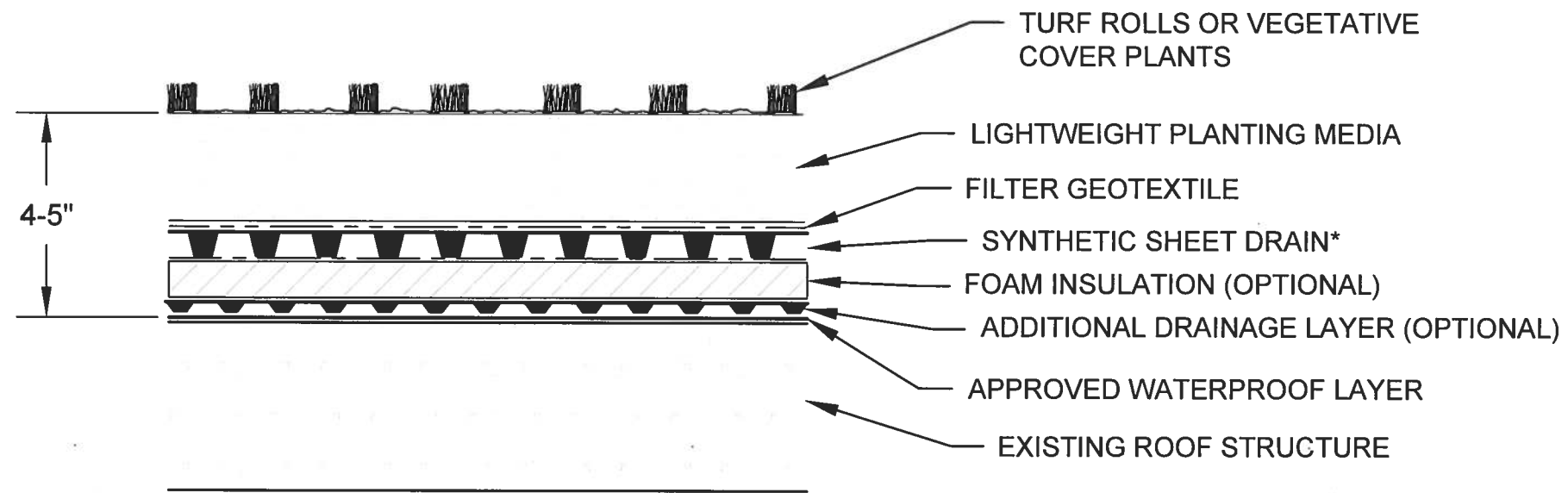
TOTAL PHOSPHORUS SHOULD NOT EXCEED 15 PPM

VEGETATION SPECIFICATIONS

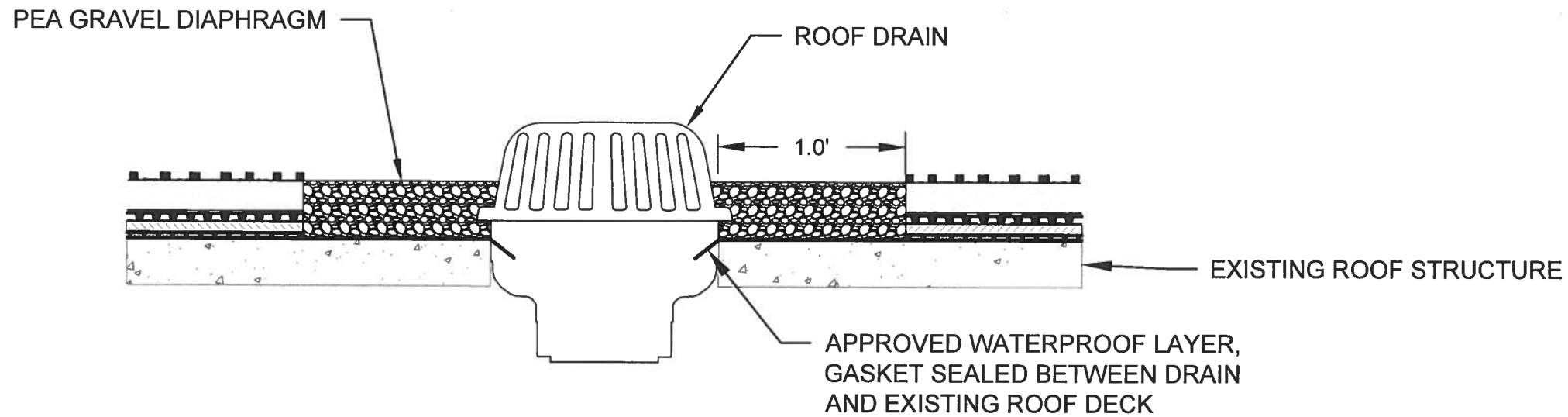
FOR BIOSWALES TO FUNCTION PROPERLY AS STORMWATER TREATMENT AND BLEND INTO THE LANDSCAPING, VEGETATION SELECTION IS CRUCIAL. APPROPRIATE VEGETATION WILL HAVE THE FOLLOWING CHARACTERISTICS:

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2. IT IS RECOMMENDED THAT A MINIMUM OF THREE TREE, THREE SHRUBS, AND THREE HERBACEOUS GROUNDCOVER SPECIES BE INCORPORATED TO PROTECT AGAINST FACILITY FAILURE FROM DISEASE AND INSECT INFESTATIONS OF A SINGLE SPECIES. PLANT ROOTING DEPTHS MUST NOT DAMAGE THE UNDERDRAIN, IF PRESENT. SLOTTED OR PERFORATED UNDERDRAIN PIPE MUST BE MORE THAN 5 FEET FROM TREE LOCATIONS (IF SPACE ALLOWS).
3. NATIVE PLANT SPECIES THAT ARE NOT INVASIVE AND DO NOT REQUIRE CHEMICAL INPUTS ARE RECOMMENDED TO BE USED TO THE MAXIMUM EXTENT PRACTICABLE.
4. SHADE TREES SHOULD BE FREE OF BRANCHES FOR THE BOTTOM 1/3 OF THEIR TOTAL HEIGHT AND LINES OF SITE SHOULD BE MAINTAINED WITH PLANTING ALONG THE TRANSPORTATION CORRIDOR.

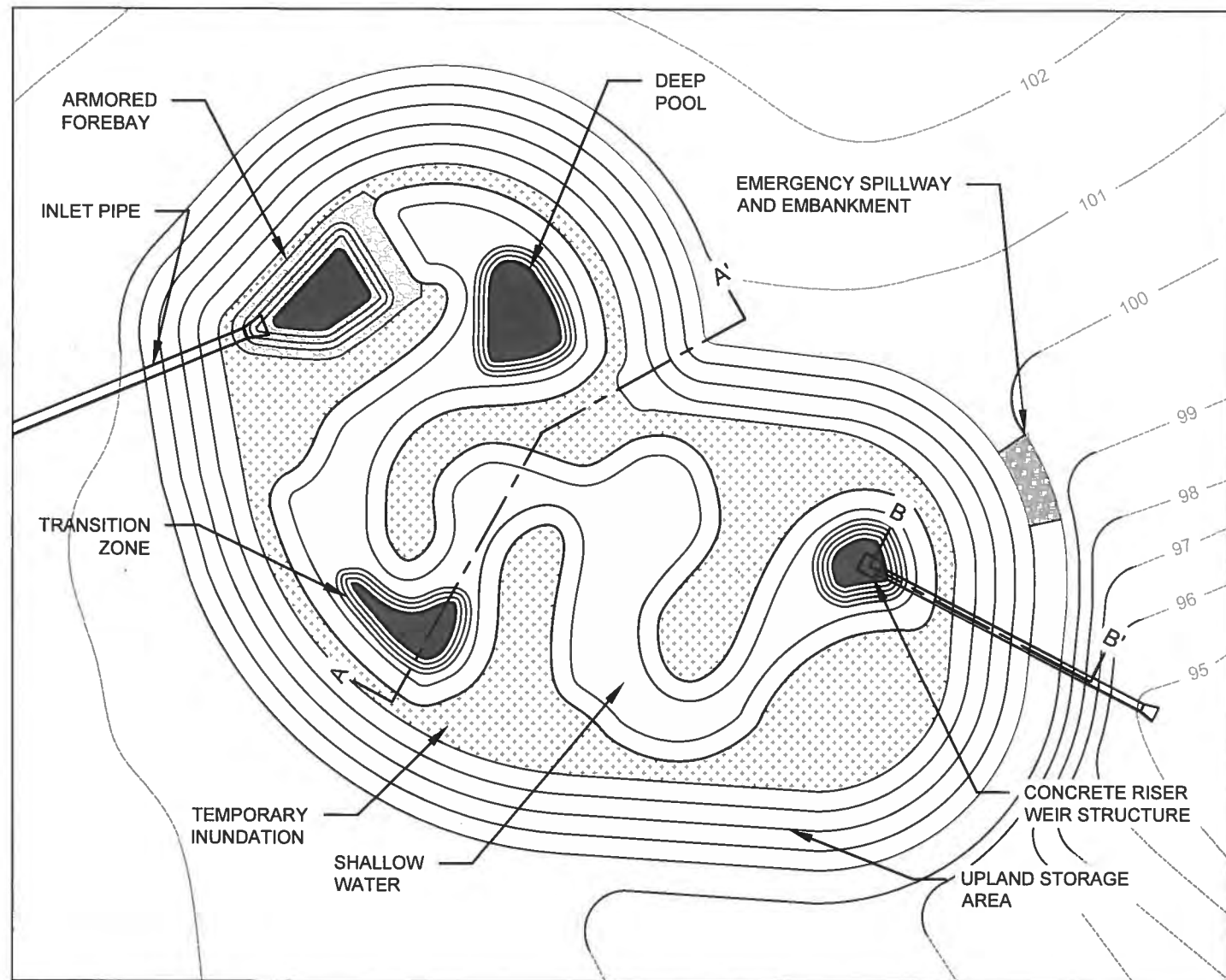
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SAN ANTONIO RIVER AUTHORITY <small>CAPITAL IMPROVEMENTS MANAGEMENT SERVICES DEPARTMENT</small>		
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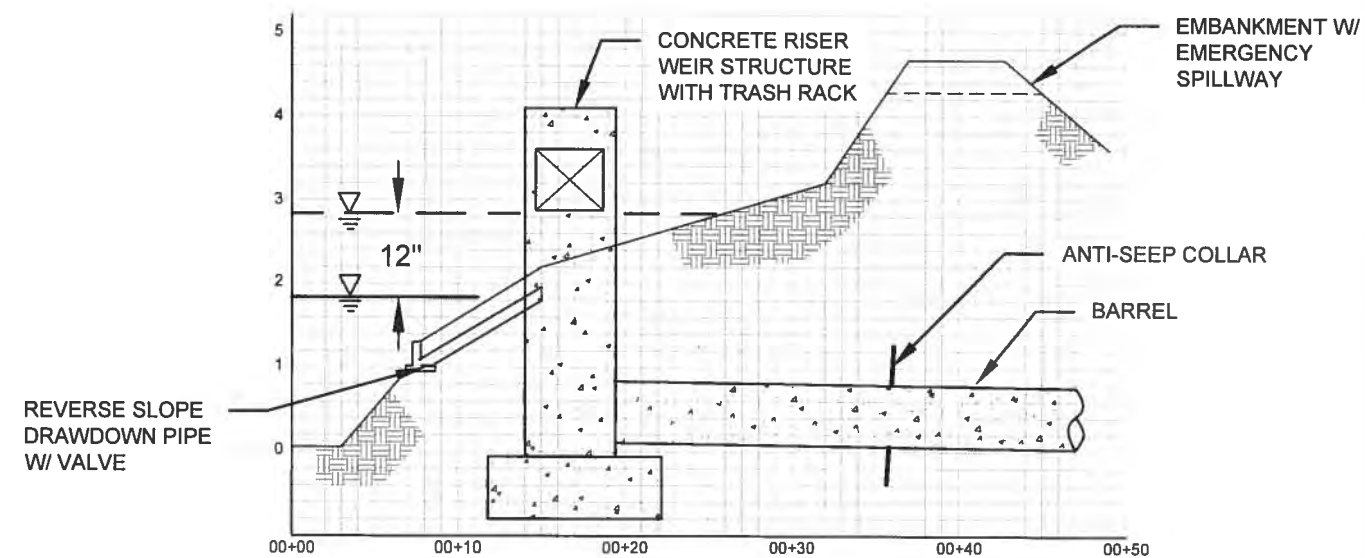
*TO GUTTERS OR ROOF DRAINS



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CITY OF SAN ANTONIO CAPITAL IMPROVEMENTS MANAGEMENT SERVICES DEPARTMENT		
GREEN ROOF		
<small>___% SUBMITTAL</small>	<small>PROJECT NO.:</small> _____	<small>DATE:</small> _____
<small>DRWN. BY:</small> _____	<small>DSGN. BY:</small> _____	<small>CHKD. BY:</small> _____
		<small>SHEET NO.:</small> ___ OF ___



PLAN VIEW (TYP.)



PROFILE B-B'

WETLAND ZONES

- DEEP POOLS 15-20% OF WETLAND SURFACE AREA (INCLUDING FOREBAY) 18- TO 36-INCHES-DEEP
- TRANSITION 10-15% OF WETLAND SURFACE AREA TRANSITION BETWEEN DEEP POOL AND SHALLOW WATER, 12-18 INCHES DEEP, MAXIMUM SLOPES OF 1.5:1
- SHALLOW WATER 40% OF WETLAND SURFACE AREA, 3- TO 6-INCHES-DEEP, FLAT OR 6:1 SLOPE (AT LEAST 6-FOOT RADIUS AROUND ALL TRANSITION ZONES/DEEP POOLS TO PROVIDE SAFETY SHELF)
- TEMPORARY PONDING 30-40% OF WETLAND SURFACE AREA, UP TO 12-INCHES-DEEP, 3:1 SLOPES
- DETENTION STORAGE/UPLAND ADDITIONAL PONDING DEPTH CAN BE PROVIDED FOR PEAK FLOW MITIGATION, AS NEEDED, BUT DEPTH SHOULD GENERALLY NOT EXCEED 4 FEET ABOVE THE PERMANENT POOL ELEVATION

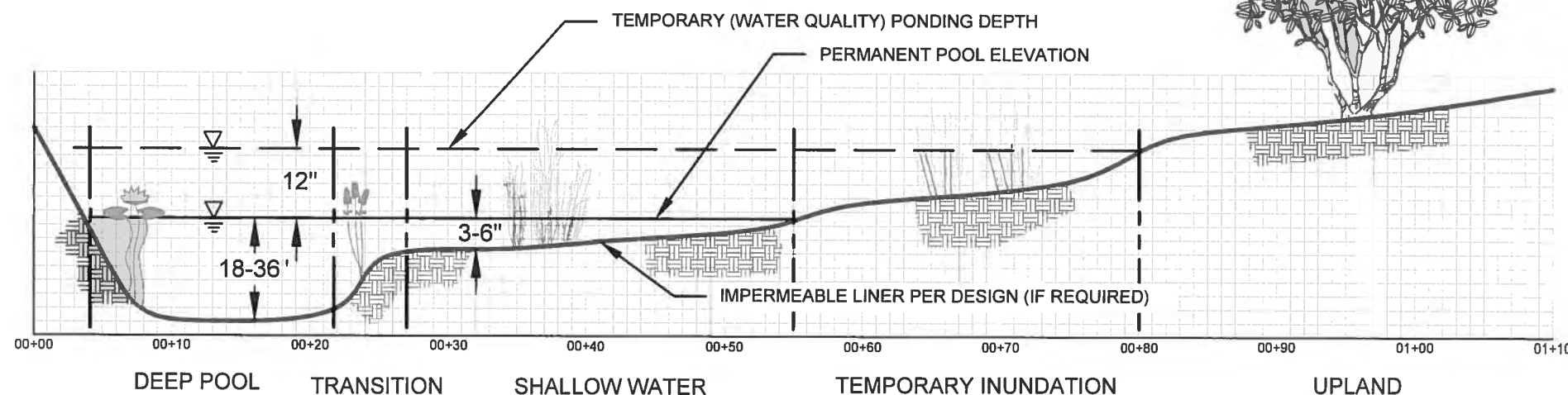
TOPSOIL

1-4 INCHES OF TOPSOIL SHOULD BE APPLIED TO SUPPORT PLANT GROWTH. DEPTH DEPENDS ON SPECIFIED PLANTINGS AND UNDERLYING SOIL CHARACTERISTICS. TOPSOIL NATURAL, FRIABLE SOIL REPRESENTATIVE OF PRODUCTIVE, WELL-DRAINED SOILS IN THE AREA. IT SHALL BE FREE OF SUBSOIL, STUMPS, ROCKS LARGER THAN 1-INCH DIAMETER, BRUSH WEEDS, TOXIC SUBSTANCES, AND OTHER MATERIAL DETRIMENTAL TO PLANT GROWTH. LOW PHOSPHORUS (TP < 15 PPM) WITH PH 5.5-7.

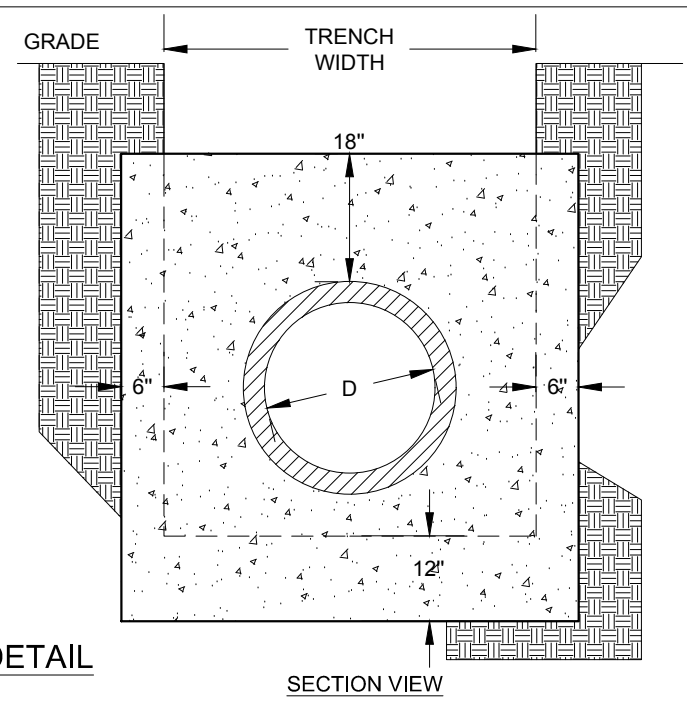
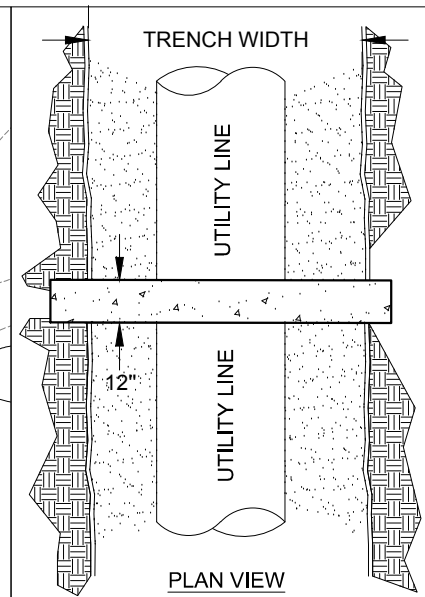
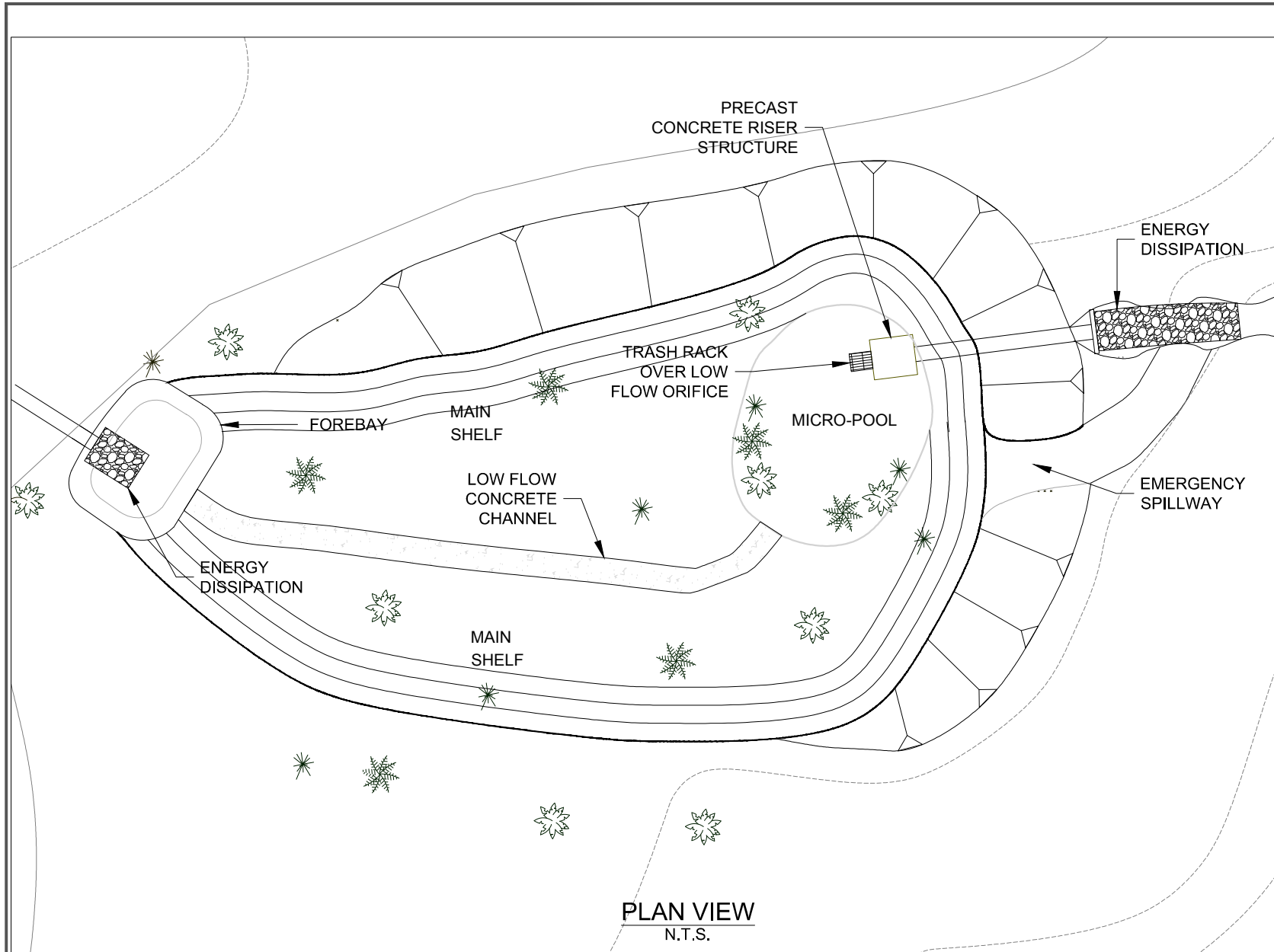
BMP FUNCTION

- FOREBAY SHOULD CONSTITUTE 10% OF THE TOTAL PERMANENT POOL SURFACE AREA
- RATE OF WATER LOSS DURING DRY MONTHS SHOULD NOT EXCEED SUPPLY FROM GROUNDWATER, BASEFLOW OR RUNOFF TO ENSURE WATER IS MAINTAINED IN PERMANENT POOLS
- THE MINIMUM LENGTH-TO-WIDTH (L/W) RATIO SHOULD BE 2:1, BUT L/W SHOULD BE MAXIMIZED BY CREATING A SINUOUS FLOW PATH AND PLACING THE OUTLET AS FAR FROM THE INLET AS POSSIBLE
- 6-12 INCHES OF TEMPORARY PONDING SHALL BE PROVIDED ABOVE THE NORMAL POOL ELEVATION
- DRAW DOWN ORIFICE IS DESIGNED TO DISCHARGE THE WATER QUALITY VOLUME IN 2 TO 5 DAYS (LONGER TIMES MAXIMIZE TREATMENT EFFICIENCY)

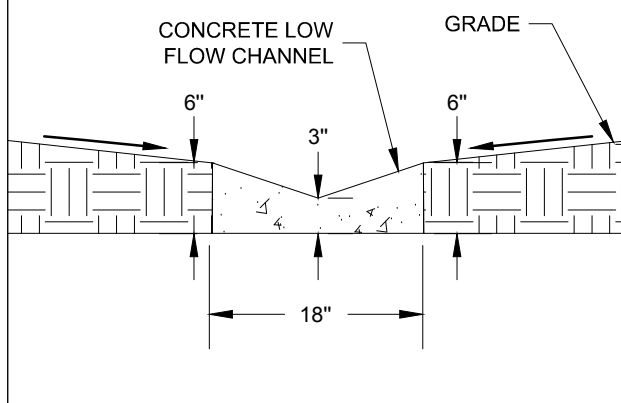
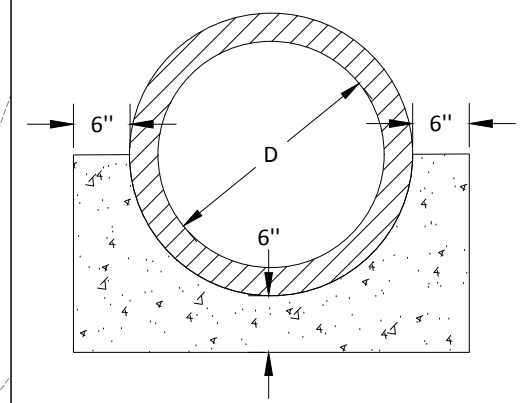
SECTION A-A'



CONSULTANT NAME		
STREET NUMBER AND ADDRESS		
SAN ANTONIO RIVER AUTHORITY		
CONSTRUCTED WETLAND		
DATE: _____	PROJECT NO.: _____	% SUBMITTAL _____
CHKD. BY: _____	DSGN. BY: _____	DRWN BY: _____
SHEET NO.: _____	OF _____	

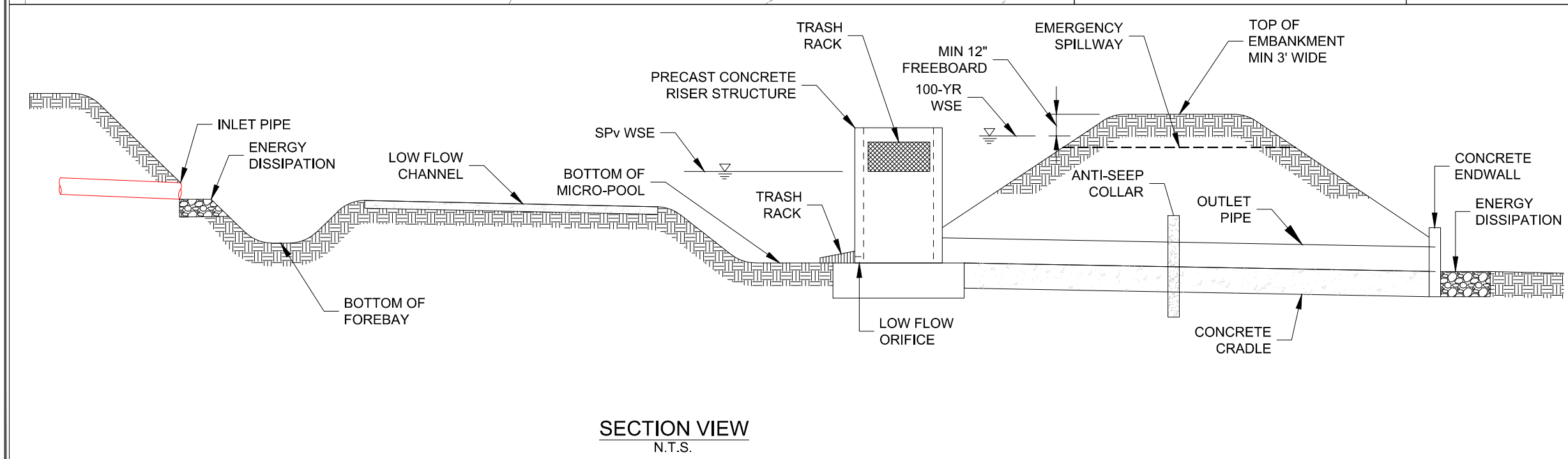


ANTI-SEEP COLLAR DETAIL
N.T.S.

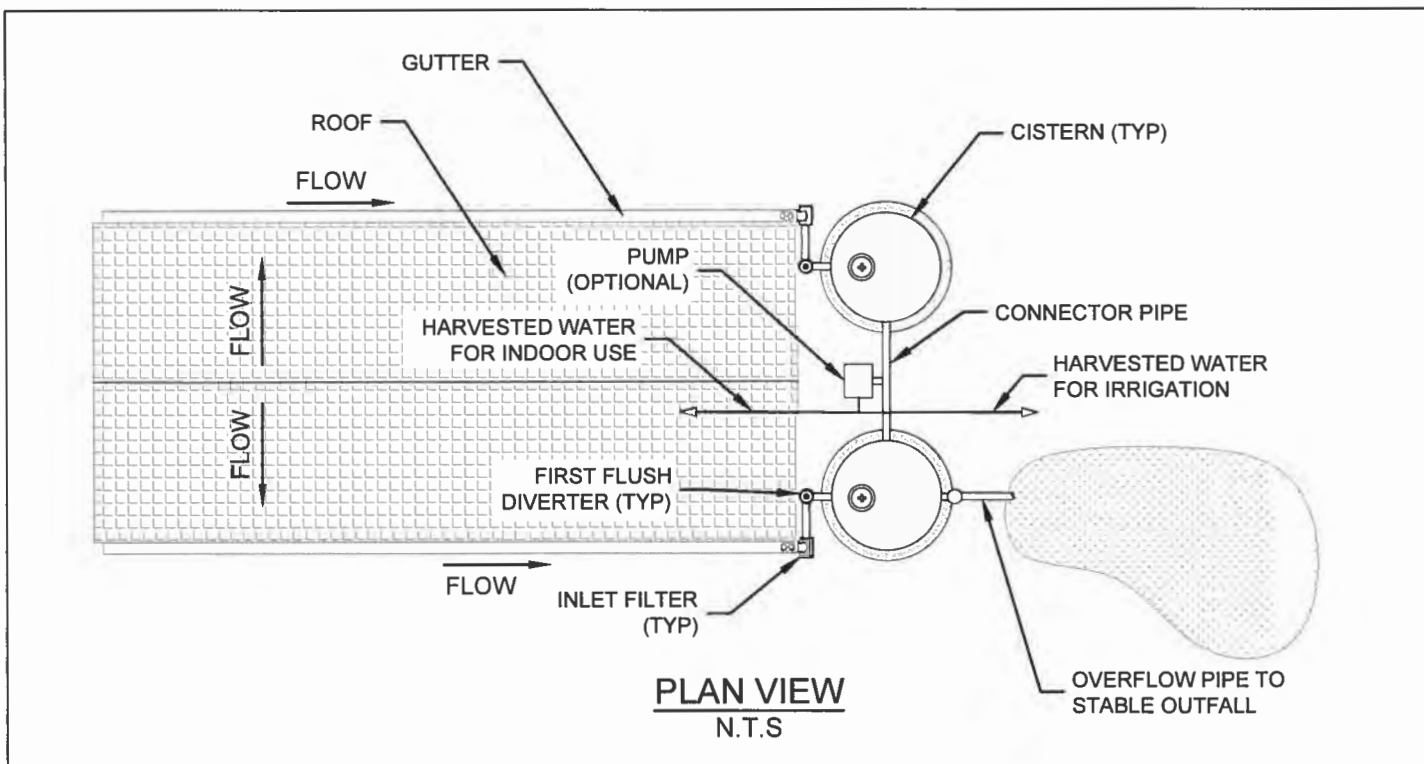
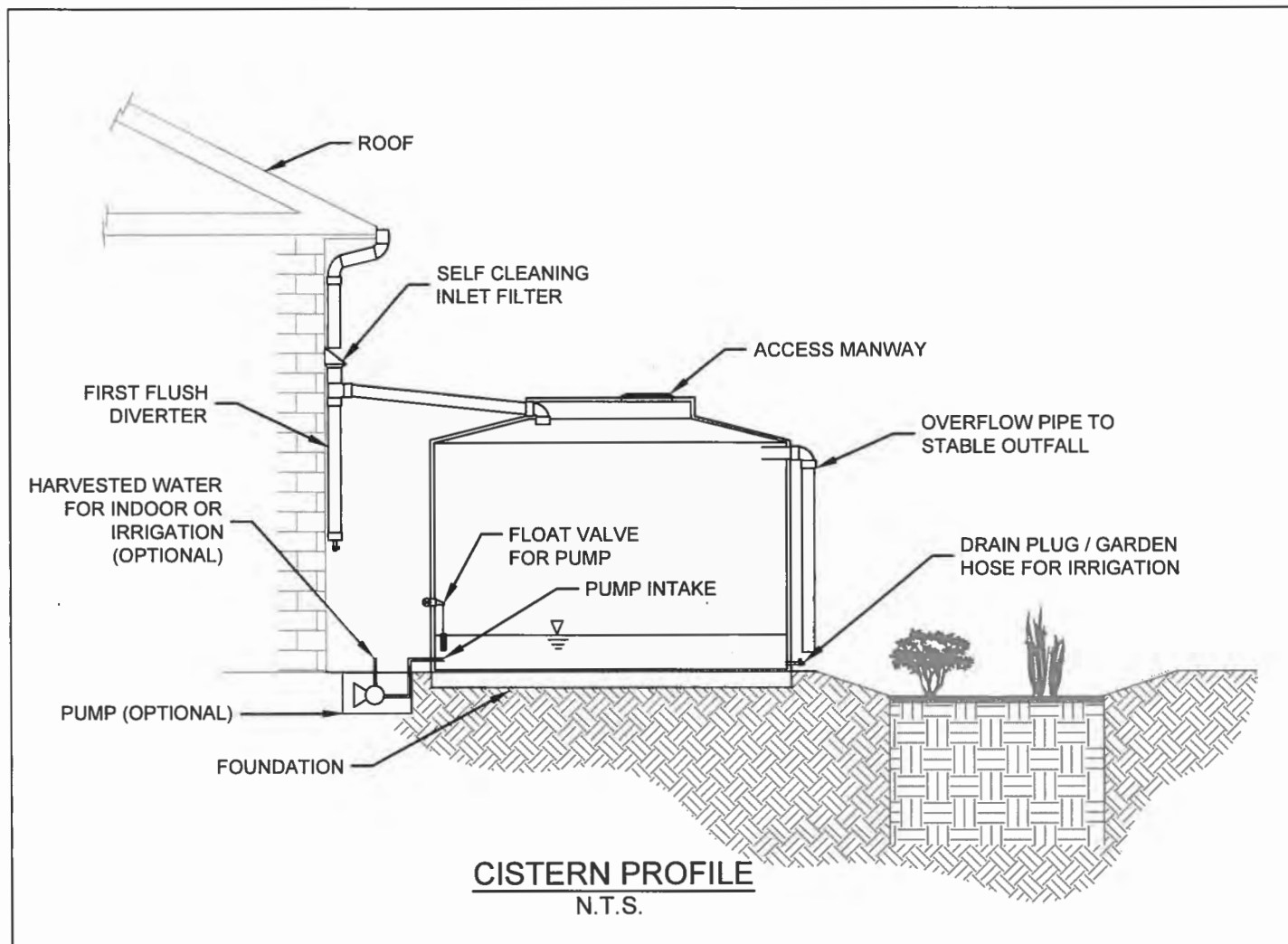


CONCRETE CRADLE DETAIL
N.T.S.

LOW FLOW CHANNEL DETAIL
N.T.S.



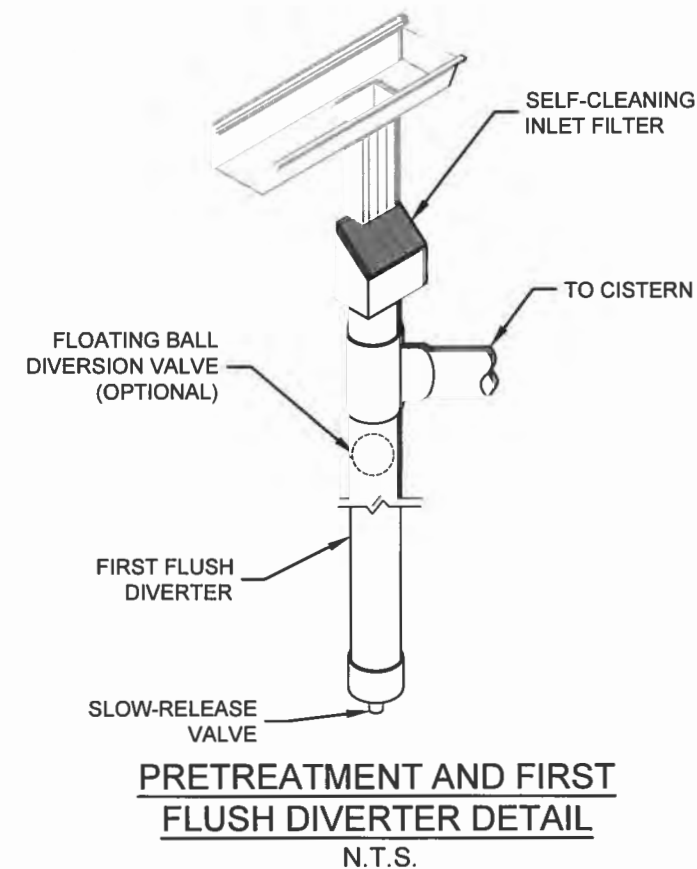
CONSULTANT NAME
 STREET NUMBER AND ADDRESS
SAN ANTONIO RIVER AUTHORITY
EXTENDED DETENTION BASIN



NOTES: CAUTIONARY SIGNAGE, PIPE COLOR, AND LOCKING FEATURES

PER SECTION 608.8 AND SECTION C104.4 OF THE CITY OF SAN ANTONIO AMENDMENTS TO THE INTERNATIONAL PLUMBING CODE, CLEAR AND OBVIOUS SIGNAGE MUST BE PROVIDED WHEREVER HARVESTED RAINWATER IS USED. SIGNS WITH PURPLE BACKGROUND (PANTONE COLOR #512) AND BLACK LETTERING SHOULD READ "CAUTION: RECLAIMED WATER, DO NOT DRINK" IN ENGLISH AND SPANISH. AREAS REQUIRING SIGNAGE INCLUDE ENTRANCES TO ROOMS (INCLUDING MECHANICAL ROOMS) WHERE HARVESTED WATER IS PIPED OR USED, IRRIGATION AND AUTOMOBILE WASHING HOSES, LOW-FLOW OUTLET ORIFICES, TOILET TANKS THAT USE HARVESTED WATER FOR FLUSHING, AND ANY SPIGOTS, DRAWDOWN PIPES, OR ACCESS HATCHES. SPECIFIC SIGNAGE LANGUAGE FOR THESE USES IS PROVIDED IN SECTION C104.7 OF THE CITY OF SAN ANTONIO AMENDMENTS TO THE INTERNATIONAL PLUMBING CODE.

ALL PIPES AND HOSES USED TO CONVEY HARVESTED WATER SHOULD BE PURPLE IN COLOR (PANTONE COLOR #512) OR CONTINUOUSLY WRAPPED WITH PURPLE MYLAR TAPE (PER SECTION C104.4 OF THE CITY OF SAN ANTONIO AMENDMENTS TO THE INTERNATIONAL PLUMBING CODE) TO INDICATE THAT THE WATER IS NOT SAFE TO DRINK. TAPE-WRAPPED PIPE SHALL DISPLAY THE WARNING PROVIDED ABOVE IN NOMINAL 1/2-INCH BLACK, UPPERCASE LETTERING IN TWO PARALLEL LINES SUCH THAT AFTER WRAPPING THE PIPE A FULL LINE OF TEXT IS VISIBLE. PIPES THAT ARE COMPLETELY COLORED PURPLE SHALL DISPLAY THE WARNING ON BOTH SIDES AT INTERVALS NOT EXCEEDING 3 FEET. ADDITIONALLY, ALL VALVES (EXCEPT FIXTURE SUPPLY CONTROL VALVES) MUST BE EQUIPPED WITH LOCKING FEATURES.



CONSULTANT NAME		
STREET NUMBER AND ADDRESS		
SAN ANTONIO RIVER AUTHORITY		
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% SUBMITTAL	PROJECT NO.:	DATE
DRWN BY	DSGN BY	CHKD BY
		SHEET NO. OF

Appendix D. Fact Sheets

Siting and Suitability

Bioretention areas offer flexibility in design and can easily be incorporated into new or existing infrastructure such as parking lot islands and edges, street rights-of-way and medians, roundabouts, pedestrian walkways, public transit stops, or building drainage areas. The available space and site topography often dictate the geometry and size of the bioretention areas. Additional site objectives include incorporation into the site's natural hydrologic regime and further enhancement of natural landscape features in an urban setting. See Chapter 3 for details.

Drainage Area: Less than 5 acres and fully stabilized.

Aquifer Protection Zones and Karst: Use impermeable liner to protect subsurface resources and prevent sinkholes.

Head Requirements: Bioretention typically requires a minimum of 2.5 to 3.5 ft of elevation difference between the inlet and outlet to the receiving storm drain network.

Slopes: Slopes draining to bioretention should be 15% or less, side slopes should be 3:1 (H:V) or flatter, and internal longitudinal slope should be 2% or less.

Setbacks: Provide 10-ft setback from structures/foundations, 100-ft setback from septic fields and water supply wells, and 50-ft setback from steep slopes.

Water Table & Bedrock: At least 3 ft separation must be provided between bottom of cut (subgrade) and seasonal high water table, bedrock, or other restrictive features.

Soil Type: Bioretention can be used in any soils. If subsoil infiltration is less than 0.5 in/hr, an underdrain should be installed. A liner may be needed if subsoils contain expansive clays or calcareous minerals.

Areas of Concern: Infiltration is not allowed at sites with known soil contamination or *hot spots*, such as gas stations. An appropriate impermeable liner must be used in areas of concern.

Design Considerations & Specifications

(see Appendix B for details)

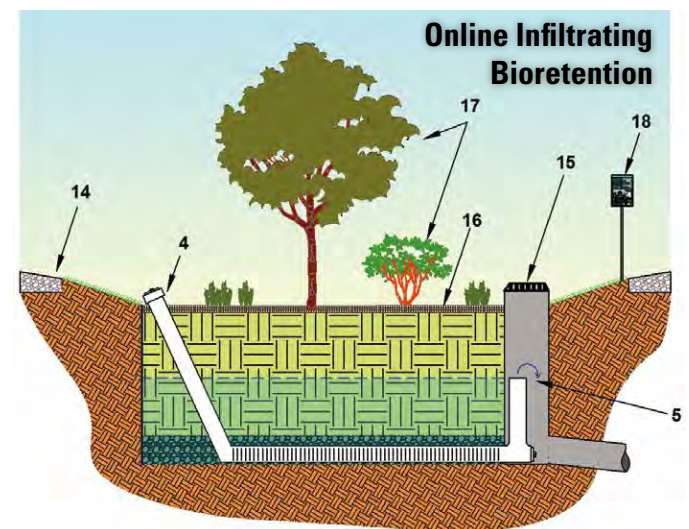
Design Component	General Specification
Drainage Design	1 Impermeable liner If non-infiltrating (per geotechnical investigation), use clay liner, geomembrane liner, or concrete.
	2 Lateral hydraulic restriction barriers May use concrete or geomembrane to restrict lateral flows to adjacent subgrades, foundations, or utilities.
	3 Underdrain/Infiltration Underdrain required if subsoil infiltration < 0.5 in/hr. Schedule 40 PVC pipe with perforations (slots or holes) every 6 inches. 4-inch diameter lateral pipes spaced no more than 10 ft on center should join a 6-inch collector pipe. If design is fully-infiltrating, ensure that subgrade compaction is minimized.
	4 Cleanouts/Observation Wells Provide cleanout ports/observation wells for each underdrain pipe at spacing consistent with local regulations.
	5 Internal Water Storage (IWS) If using underdrain, the underdrain outlet can be elevated to create a sump for additional moisture retention to promote plant survival and treatment. Top of IWS should be greater than 18 inches below surface.
	6 Temporary Ponding Depth 6–18 inches (6–12 inches near schools or in residential areas); average ponding depth of 9 inches is recommended.
	7 Drawdown Time Surface drawdown: 12–24 hrs. Subsurface dewatering: 48 hrs.
Soil Media	8 Soil Media Depth 2–4 feet (deeper for better pollutant removal, hydrologic benefits, and deeper rooting depths).
	9 Soil Media Composition 85–88% sand, 8–12% fines, 2–5% plant-derived organic matter (animal wastes or byproducts should never be applied).
	10 Media Permeability 1–6 in/hr infiltration rate (1–2 in/hr recommended).
	11 Chemical Analysis Total phosphorus < 15 ppm, pH 6–8, CEC > 5 meq/100 g soil.
	12 Drainage Layer Separate media from underdrain with 2 to 4 inches of washed sand (ASTM C-33), followed by 2 inches of choking stone (ASTM No. 8) over a 1.5 ft envelope of ASTM No. 57 stone.
Routing	13 Inlet Provide stabilized inlets and energy dissipation.
	14 Pretreatment Rock armored forebay (concentrated flow), gravel fringe and vegetated filter strip (sheet flow), or vegetated swale.
	15 Outlet Configuration Online: All runoff is routed through system—install an elevated overflow structure or weir at the elevation of maximum ponding. Offline: Only treated volume is diverted to system—install a diversion structure or allow bypass of high flows.
Landscape	16 Mulch Dimensional chipped hardwood or triple shredded, well-aged hardwood mulch 3-inches-deep.
	17 Vegetation Native, deep rooting, drought tolerant plants.
	18 Multi-Use Benefits Provide educational signage, artwork, or wildlife amenities.

Maintenance Considerations (see Appendix F for detailed checklist)

Task	Frequency	Indicator Maintenance is Needed	Maintenance Notes
Catchment inspection	Weekly or biweekly with routine property maintenance	Excessive sediment, trash, and/or debris accumulation on the surface of bioretention	Permanently stabilize any exposed soil and remove any accumulated sediment. Adjacent pervious areas may need to be regraded.
Inlet inspection		Internal erosion or excessive sediment, trash, and/or debris accumulation	Check for sediment accumulation to ensure that flow into the bioretention is as designed. Remove any accumulated sediment.
Litter/leaf removal and misc. upkeep		Accumulation of litter and debris within bioretention area, mulch around outlet, internal erosion	Litter, leaves, and debris should be removed to reduce the risk of outlet clogging, reduce nutrient inputs to the bioretention area, and to improve facility aesthetics. Erosion should be repaired and stabilized.
Pruning	1–2 times/year	Overgrown vegetation that interferes with access, lines of sight, or safety	Nutrients in runoff often cause bioretention vegetation to flourish.
Mowing	2–12 times/year	Overgrown vegetation that interferes with access, lines of sight, or safety	Frequency depends on location and desired aesthetic appeal and type of vegetation.
Outlet inspection	1 time/year	Erosion at outlet	Remove any accumulated mulch or sediment.
Mulch removal and replacement	1 time/2–3 years	Less than 3 inches of mulch remaining	Remove decomposed fraction and top off with fresh mulch to a total depth of 3 inches
Remove and replace dead plants	1 time/year	Dead plants	Plant die-off tends to be highest during the first year (commonly 10% or greater). Survival rates increase with time.
Temporary Watering	1 time/2–3 days for first 1–2 months	Until establishment and during severely-droughty weather	Watering after the initial year might be required.
Fertilization	1 time initially	Upon planting	One-time spot fertilization for first year vegetation.



This schematic represents an offline situation where higher flows bypass the system to the existing downstream network. Infiltration is restricted due to hypothetical subsurface conflicts and adjacency to infrastructure.



This schematic represents an online situation where all flow is routed through the system—an outlet structure is provided to allow overflow during higher flow events. The underdrain is upturned to enhance capture and infiltration of runoff and to improve soil moisture for plant survival.

Description

Bioretention areas are small-scale, vegetated depressions designed to provide stormwater storage and filtration through engineered media. Using detention, sedimentation, filtration and adsorption, bioretention enhances the removal of contaminants from stormwater by both plants and soils.

Bioretention can also incorporate pretreatment (i.e., vegetated filter strips, vegetated swales or settling forebays), allowing increased sedimentation and capture of debris from heavily trafficked areas. Finally, bioretention can be used in-line with traditional stormwater conveyance systems.

Treatment Efficiency

Parameter	Efficiency
Runoff Volume	High (unlined)/Low (lined)
Sediment	High
Nutrients	Medium
Pathogens	High
Metals	High
Oil & Grease	High
Organics	High



Siting and Suitability

Bioswales are highly versatile stormwater BMPs that effectively reduce pollutants. With a narrow width, bioswales can be integrated into site plans with various configurations and components. Ideal sites for bioswales include the right-of-way of linear transportation corridors and along borders or medians of parking lots. In heavily trafficked areas, curb cuts can be used to delineate boundaries. Bioswales can be combined with other basic and stormwater runoff BMPs to form a treatment train, reducing the required size of a single BMP unit.

Drainage Area: Less than 2 acres and fully stabilized.

Aquifer Protection Zones and Karst: Use impermeable liner to protect subsurface resources and prevent sinkholes.

Head Requirements: Bioswale typically requires a minimum of 2.5 to 3.5 ft of elevation difference between the inlet and outlet to the receiving storm drain network.

Slopes: Slopes draining to bioswale should be 15% or less, side slopes should be 3:1 (H:V) or flatter, and check dams should be used to provide longitudinal bed slopes of 2% (average slope should not exceed 5% from inlet to outlet).

Setbacks: Provide 10-ft setback from structures/foundations, 100-ft setback from septic fields and water supply wells, and 50-ft setback from steep slopes.

Water Table & Bedrock: At least 3 ft separation must be provided between bottom of cut (subgrade) and seasonal high water table, bedrock, or other restrictive features.

Soil Type: Bioswale can be used in any soils. If subsoil infiltration is less than 0.5 in/hr, an underdrain should be installed. A liner may be needed if subsoils contain expansive clays or calcareous minerals.

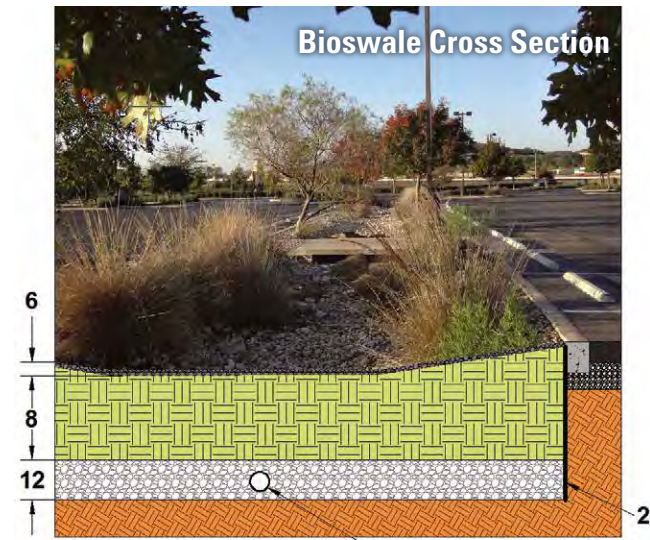
Areas of Concern: Infiltration is not allowed at sites with known soil contamination or *hot spots*, such as gas stations. An appropriate impermeable liner must be used in areas of concern.

Design Considerations & Specifications (see Appendix B for details)

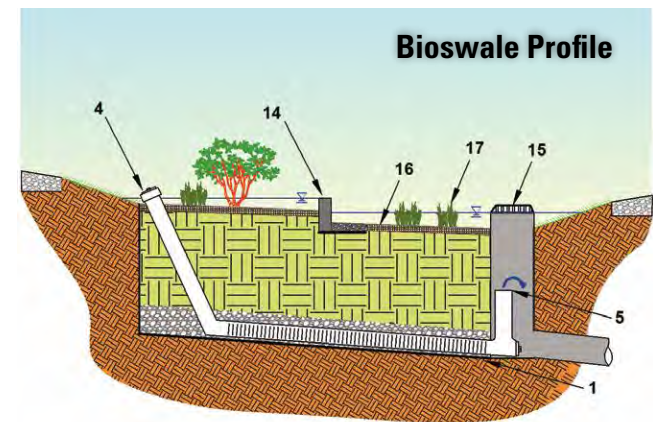
Design Component	General Specification
BMP Function	1 Impermeable liner If non-infiltrating (per geotechnical investigation), use clay liner, geomembrane liner, or concrete.
	2 Lateral hydraulic restriction barriers May use concrete or geomembrane to restrict lateral seepage to adjacent subgrades, foundations, or utilities.
	3 Underdrain/Infiltration Underdrain required if subsoil infiltration < 0.5 in/hr. Schedule 40 PVC pipe with perforations (slots or holes) every 6 inches. 4-inch diameter lateral pipes spaced no more than 10 ft on center should join a 6-inch collector pipe. If design is fully-infiltrating, ensure that subgrade compaction is minimized.
	4 Cleanouts/Observation Wells Provide cleanout ports/observation wells for each underdrain pipe at spacing consistent with local regulations.
	5 Internal Water Storage (IWS) If using underdrain, the underdrain outlet can be elevated to create a sump for additional moisture retention to promote plant survival and treatment. Top of IWS should be greater than 18 inches below surface.
	6 Temporary Ponding Depth Use check dams to provide 6–18 inches (6–12 inches near schools or in residential areas); average ponding depth of 9 inches is recommended.
	7 Drawdown Time Surface drawdown: 12–24 hrs Subsurface dewatering: 48 hrs.
Soil Media	8 Soil Media Depth 2–4 feet (deeper for better pollutant removal, hydrologic benefits, and deeper rooting depths).
	9 Soil Media Composition 85–88% sand, 8–12% fines, 2–5% plant-derived organic matter (animal wastes or byproducts should never be applied).
	10 Media Permeability 1–6 in/hr infiltration rate (1–2 in/hr recommended).
	11 Chemical Analysis Total phosphorus < 15 ppm, pH 6–8, CEC > 5 meq/100 g soil.
	12 Drainage Layer Separate media from underdrain with 2 to 4 inches of washed concrete sand (ASTM C-33), followed by 2 inches of choking stone (ASTM No. 8) over a 1.5 ft envelope of ASTM No. 57 stone.
Routing	13 Inlet/Pretreatment Provide stabilized inlets and energy dissipation. Install rock armored forebay for concentrated flows, gravel fringe and vegetated filter strip for sheet flows.
	14 Slope and Grade Control If necessary, use check dams to maintain maximum 2% bed slope. Check dams should extend sufficiently deep to prevent piping (undercutting) below the check dam.
	15 Outlet Configuration Online: All runoff is routed through system—install an elevated overflow structure or weir at the elevation of maximum ponding. Offline: Only treated volume is diverted to system—install a diversion structure or allow bypass of high flows.
Landscape	16 Mulch Dimensional chipped hardwood or triple shredded, well-aged hardwood mulch 3-inches-deep.
	17 Vegetation Native, deep rooting, drought tolerant plants.
18 Multi-Use Benefits Provide educational signage, artwork, or wildlife amenities.	

Maintenance Considerations (see Appendix F for detailed checklist)

Task	Frequency	Indicator Maintenance is Needed	Maintenance Notes
Catchment inspection	Weekly or biweekly with routine property maintenance	Excessive sediment, trash, and/or debris accumulation on the surface of bioswale	Permanently stabilize any exposed soil and remove any accumulated sediment. Adjacent pervious areas may need to be regraded.
Inlet inspection		Internal erosion or excessive sediment, trash, and/or debris accumulation	Check for sediment accumulation to ensure that flow into the bioswale is as designed. Remove any accumulated sediment.
Litter/leaf removal and misc. upkeep		Accumulation of litter and debris within bioswale area, mulch around outlet, internal erosion	Litter, leaves, and debris should be removed to reduce the risk of outlet clogging, reduce nutrient inputs to the bioretention area, and to improve facility aesthetics. Erosion should be repaired and stabilized.
Pruning	1–2 times/year	Overgrown vegetation that interferes with access, lines of sight, or safety	Nutrients in runoff often cause bioretention vegetation to flourish.
Mowing	2–12 times/year	Overgrown vegetation that interferes with access, lines of sight, or safety	Frequency depends on location and desired aesthetic appeal and type of vegetation.
Outlet inspection	1 time/year	Erosion at outlet	Remove any accumulated mulch or sediment.
Mulch removal and replacement	1 time/2–3 years	Less than 3 inches of mulch remaining	Remove decomposed fraction and top off with fresh mulch to a total depth of 3 inches
Remove and replace dead plants	1 time/year	Dead plants	Plant die-off tends to be highest during the first year (commonly 10% or greater). Survival rates increase with time.
Temporary Watering	1 time/2–3 days for first 1–2 months	Until establishment and during severely-droughty weather	Watering after the initial year might be required.
Fertilization	1 time initially	Upon planting	One-time spot fertilization for first year vegetation.



A bioswale captures, conveys, and filters runoff at the Rim Retail Center. Lateral hydraulic restriction barriers protect the adjacent pavement subgrade while allowing vertical infiltration.



This schematic represents an online, infiltrating bioswale where all flow is routed through the system—check dams control the longitudinal slope and ensure capture of the design storm volume. Internal water storage is provided to enhance water retention and plant survival by upturning the underdrain.

Description

Bioswales are shallow, open channels that are designed to reduce runoff volume through infiltration. Additionally, bioswales remove pollutants such as trash and debris by filtering water through vegetation within the channel. Swales can serve as conveyance for stormwater and can be used in place of traditional curbs and gutters; however, when compared to traditional conveyance systems the primary objective of a bioswale is infiltration and water quality enhancement rather than conveyance. In addition to reducing the mass of pollutants in runoff, properly maintained bioswales can enhance the aesthetics of a site.

Treatment Efficiency

Runoff Volume	High (unlined)/ Low (lined)	Bacteria	High
Sediment	High	Nutrients	Medium
Trash/debris	High	Heavy Metals	High
Organics	High	Oil & Grease	High



Siting and Suitability

The use of permeable pavement is encouraged for sites such as parking lots, driveways, pedestrian plazas, rights-of-way, and other lightly traveled areas. Numerous types and forms of permeable pavers exist and offer a range of utility, strength, and permeability. Permeable pavement must be designed to support the maximum anticipated traffic load but should not be used in highly trafficked areas. For designs that include infiltration, surrounding soils must allow for adequate infiltration. Precautions must be taken to protect soils from compaction during construction.

Aquifer Protection Zones and Karst:

Permeable pavement can be used in sensitive geology if impermeable liners and a sand filter layer are used. In areas outside the Edwards Aquifer Recharge and Transition Zones, infiltration into native subsoils is encouraged.

Available Space: Permeable pavement is typically designed to treat storm water that falls on the pavement surface area and runoff from other impervious surfaces. It is most commonly used at commercial, institutional, and residential locations in area that are traditionally impervious. Permeable pavement should not be used in high-traffic areas.

Underground Utilities: Complete a utilities inventory to ensure that site development will not interfere with or affect utilities.

Existing Buildings: Assess building effects on the site. Permeable pavement must be set away from building foundations at least 10 feet and 50 feet from steep slopes.

Water Table and Bedrock: Permeable pavement is applicable where depth from subgrade to seasonal high water table, bedrock, or other restrictive feature is 3 feet or greater.

Soil Type: Examine site compaction and soil characteristics. Minimize compaction during construction; do not place the bed bottom on compacted fill. Determine site-specific permeability; it is ideal to have well-drained soils.

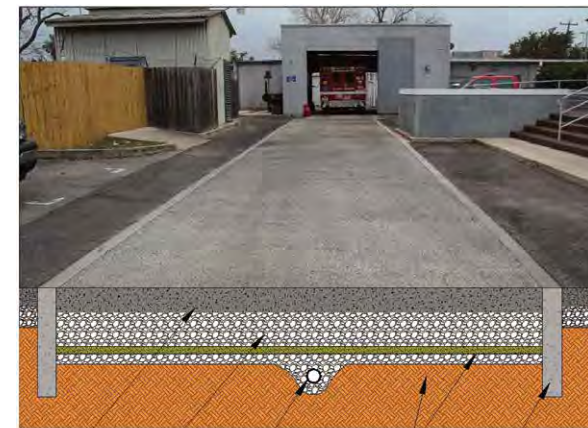
Areas of Concern: Permeable pavement that includes infiltration in design is not recommended for sites with known soil contamination or *hot spots* such as gas stations. Impermeable membrane can be used to contain flow within areas of concern.

Design Considerations & Specifications

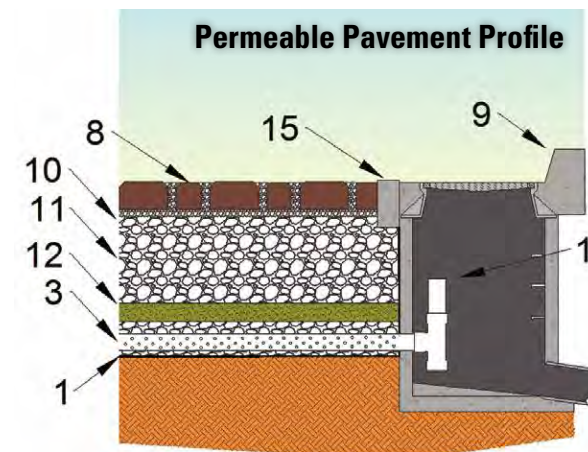
(see Appendix B for details)

Design Component	General Specification
BMP Function	1 Impermeable liner If non-infiltrating (per geotechnical investigation), use clay liner, geomembrane liner, or concrete.
	2 Lateral hydraulic restriction barriers May use concrete or geomembrane to restrict lateral seepage to adjacent subgrades, foundations, or utilities.
	3 Underdrain/Infiltration Underdrain required if subsoil infiltration < 0.5 in/hr. Schedule 40 PVC pipe with perforations (slots or holes) every 6 inches. 4-inch diameter lateral pipes should join a 6-inch collector pipe. If design is fully infiltrating, ensure that subgrade compaction is minimized.
	4 Observation Wells Provide capped observation wells to monitor drawdown.
	5 Internal Water Storage (IWS) If using underdrain in infiltrating systems, the underdrain outlet can be elevated to create a sump to enhance infiltration and treatment.
	6 Drawdown Time If using fully-lined system, provide orifice at underdrain outlet sized to release water quality volume over 2–5 days.
	7 Subgrade Slope and Geotextile Subgrade slope should be 0.5% or flatter. Baffles should be used to ensure water quality volume is retained. Geotextile should be used along perimeter of cut to prevent soil from entering the aggregate voids.
Profile	8 Surface Course Pervious concrete, porous asphalt, and permeable interlocking concrete pavers (PICP) are the preferred types of permeable pavement because detailed industry standards and certified installers are available.
	9 Temporary Ponding Depth (in Edwards Aquifer Zones) Surface ponding should be provided (by curb and gutter) to capture the design storm in the event that the permeable pavement surface clogs.
	10 Bedding Course (for PICP) Use a 2-inch bedding course of ASTM No. 8 stone.
	11 Reservoir Layer Base layer should be washed ASTM No. 57 stone (washed ASTM No. 2 may be used as a subbase layer for additional storage).
	12 Soil/Sand Filter Layer With underdrains or when subsoils are not suitable for filtration (per geotechnical investigation: min. 4-inch layer of ASTM C-33 washed sand above gravel of underdrain drainage layer. No underdrains: min. 12-inch of native subsoil as subgrade.
13 Structural Design A pavement structural analysis should be completed by a qualified and licensed professional.	
Routing	14 Large Storm Routing For poured in place systems (pervious concrete or porous asphalt): system can overflow internally or on the surface. For modular/paver-type systems (PICP): internal bypass is required to prevent upflow and transport of bedding course.
Other	15 Edge Restraints and Dividers Provide a concrete divider strip between any permeable and impermeable surfaces and around the perimeter of PICP installations.
	16 Signage Signage should prohibit activities that cause premature clogging and indicate to pedestrians and maintenance staff that the surface is intended to be permeable.
	17 Multi-Use Benefits Provide educational signage, enhanced pavement colors, or stormwater reuse systems.

Permeable Pavement Cross Section



Pervious concrete captures runoff from the Alamo Heights Fire Station. An impermeable concrete transition strip delineates the pervious concrete for maintenance personnel and functions as a hydraulic restriction barrier to protect adjacent pavement and infrastructure from lateral seepage.



This schematic represents a typical permeable pavement profile with internal water storage to enhance capture and infiltration of the design storm volume. An orifice can be provided at the invert of the underdrain to slowly dewater captured runoff in non-infiltrating systems.

Maintenance Considerations (see Appendix F for detailed checklist)

Task	Frequency	Indicator Maintenance is Needed	Maintenance Notes
Catchment inspection	Weekly or biweekly during routine property maintenance	Sediment accumulation on adjacent impervious surfaces or in voids/joints of permeable pavement	Stabilize any exposed soil and remove any accumulated sediment. Adjacent pervious areas may need to be graded to drain away from permeable pavement.
Miscellaneous upkeep	Weekly or biweekly during routine property maintenance	Trash, leaves, weeds, or other debris accumulated on permeable pavement surface	Immediately remove debris to prevent migration into permeable pavement voids. Identify source of debris and remedy problem to avoid future deposition.
Preventative vacuum/regenerative air street sweeping	Twice a year in higher sediment areas	N/A	Pavement should be swept with a vacuum power or regenerative air street sweeper at least twice per year to maintain infiltration rates.
Replace fill materials	As needed	For paver systems, whenever void space between joints becomes apparent or after vacuum sweeping	Replace bedding fill material to keep fill level with the paver surface.
Restorative vacuum/regenerative air street sweeping	As needed	Surface infiltration test indicates poor performance or water is ponding on pavement surface during rainfall	Pavement should be swept with a vacuum power or regenerative air street sweeper to restore infiltration rates.

Description

Permeable pavement allows for percolation of stormwater through subsurface aggregate and offers an alternative to conventional concrete and asphalt paving. Typically, stormwater that drains through the permeable surface is allowed to infiltrate underlying soils and excess runoff drains through perforated underdrain pipes.

Treatment Efficiency

Runoff Volume	High (unlined)/Low (lined)
Sediment	High
Nutrients	Low
Pathogens	Medium
Metals	Medium
Oil & Grease	Medium
Organics	Low



Siting and Suitability

Planter boxes require relatively little space and can be easily adapted for urban retrofits such as building and rooftop runoff catchments or into new street and sidewalk designs. Because planter boxes are typically fully-contained systems, available space presents the most significant limitation. To ensure healthy vegetation in the planter box, proper plant and media selection are important considerations for accommodating the drought, ponding fluctuations, and brief periods of saturated soil conditions.

Drainage Area: To be less than 0.35 acres and fully stabilized.

Aquifer Protection Zones and Karst: Planter boxes can be used in areas with sensitive geology, but outflow should be directed to the storm drain network or used for irrigation (per geotechnical investigation).

Underground Utilities: Complete a utilities inventory to ensure that site development will not interfere with or affect the utilities.

Existing Buildings: Assess building effects (runoff, solar shadow) on the site. When completely contained, building setbacks are less of a concern.

Water Table: Seasonal high water table should be located below the bottom of the box.

Soil Type: Soils within the drainage area must be stabilized. If planter boxes are fully contained, local soils must provide structural support.

Areas of Concern: Fully-contained planter boxes can be used in areas with known soil contamination or in *hot spots*.

Design Considerations & Specifications

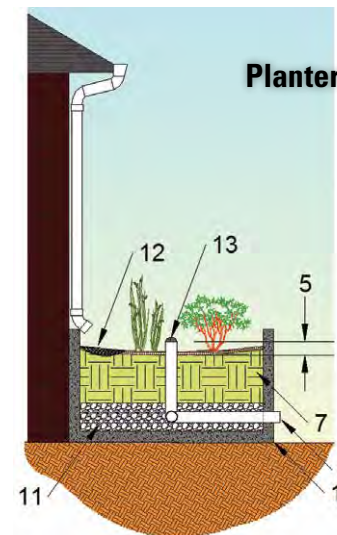
(see Appendix B for details)

Design Component/Consideration	General Specification		
BMP Function	1	Impermeable liner	Planter boxes are typically contained within a concrete vault.
	2	Underdrain (required)	Underdrain required if subsoil infiltration < 0.5 in/hr. Schedule 40 PVC pipe with perforations (slots or holes) every 6 inches. 4-inch diameter lateral pipes spaced no more than 10 ft on center should join a 6-inch collector pipe. If design is fully infiltrating, ensure that subgrade compaction is minimized.
	3	Cleanouts/Observation Wells	Provide cleanout ports/observation wells for each underdrain pipe at spacing consistent with local regulations.
	4	Internal Water Storage (IWS)	With careful plant selection, the outlet can be slightly elevated to create a sump for additional moisture retention to promote plant survival and enhanced treatment. Top of IWS should be greater than 18 inches below surface.
	5	Temporary Ponding Depth	Provide 6–18 inches surface ponding (6–12 inches near schools or in residential areas); average ponding depth of 9 inches is recommended.
	6	Drawdown Time	Surface drawdown: 12–24 hrs, Subsurface dewatering: 48 hrs.
Soil Media	7	Soil Media Depth	2–4 feet (deeper for better pollutant removal, hydrologic benefits, and deeper rooting depths).
	8	Soil Media Composition	85–88% sand, 8–12% fines, 2–5% plant-derived organic matter (animal wastes or byproducts should never be applied).
	9	Media Permeability	1–6 in/hr infiltration rate (1–2 in/hr recommended).
	10	Chemical Analysis	Total phosphorus < 15 ppm, pH 6–8, CEC > 5 meq/100 g soil.
	11	Drainage Layer	Separate soil media from underdrain with 2 to 4 inches of washed concrete sand (ASTM C33), followed by 2 inches of choking stone (ASTM No. 8) over a 1.5 ft envelope of ASTM No. 57 stone.
Routing	12	Inlet/ Pretreatment	Provide stabilized inlets and energy dissipation. Install rock armored forebay, gravel splash pad, or upturn incoming pipes.
	13	Outlet Configuration	Online: All runoff is routed through system—install an elevated overflow structure or weir at the elevation of maximum ponding. Offline: Only treated volume is diverted to system—install a diversion structure or allow bypass of high flows.
Landscape	14	Mulch	Dimensional chipped hardwood or triple shredded, well-aged hardwood mulch 3-inches-deep.
	15	Vegetation	Native, deep rooting, drought tolerant plants.
	16	Multi-Use Benefits	Provide educational signage, artwork, or wildlife habitat.

Planter Box at Sunset Depot (rendering)



This rendering illustrates an example of a planter box retrofit to an existing historical building.



Planter Box Cross Section

This figure shows the major components of a planter box.

Maintenance Considerations (see Appendix F for detailed checklist)

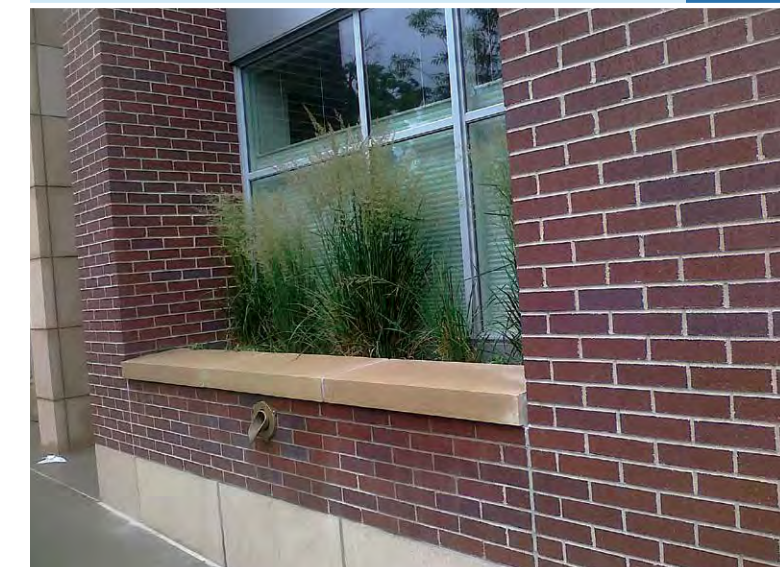
Task	Frequency	Indicator Maintenance is Needed	Maintenance Notes
Catchment inspection	Weekly or biweekly with routine property maintenance	Excessive sediment, trash, and/or debris accumulation on the surface of bioswale	Permanently stabilize any exposed soil and remove any accumulated sediment. Adjacent pervious areas may need to be regraded.
Inlet inspection		Internal erosion or excessive sediment, trash, and/or debris accumulation	Check for sediment accumulation to ensure that flow into the bioswale is as designed. Remove any accumulated sediment.
Litter/leaf removal and misc. upkeep		Accumulation of litter and debris within bioswale area, mulch around outlet, internal erosion	Litter, leaves, and debris should be removed to reduce the risk of outlet clogging, reduce nutrient inputs to the bioretention area, and to improve facility aesthetics. Erosion should be repaired and stabilized.
Pruning	1–2 times/year	Overgrown vegetation that interferes with access, lines of sight, or safety	Nutrients in runoff often cause bioretention vegetation to flourish.
Mowing	2–12 times/year	Overgrown vegetation that interferes with access, lines of sight, or safety	Frequency depends on location and desired aesthetic appeal and type of vegetation.
Outlet inspection	1 time/year	Erosion at outlet	Remove any accumulated mulch or sediment.
Mulch removal and replacement	1 time/2–3 years	Less than 3 inches of mulch remaining	Remove decomposed fraction and top off with fresh mulch to a total depth of 3 inches
Remove and replace dead plants	1 time/year	Dead plants	Plant die-off tends to be highest during the first year (commonly 10% or greater). Survival rates increase with time.
Temporary Watering	1 time/2–3 days for first 1–2 months	Until establishment and during severely-droughty weather	Watering after the initial year might be required.
Fertilization	1 time initially	Upon planting	One-time spot fertilization for first year vegetation.

Description

Planter boxes are vegetated BMP units that capture, temporarily store, and filter storm water runoff. The vegetation, ponding areas, and soil media in the planter boxes remove contaminants and retain storm water flows from small drainage areas before directing the treated storm water to an underdrain system. Typically, planter boxes are completely contained systems; for this reason, they can be used in areas where geotechnical constraints prevent or limit infiltration or in areas of concern where infiltration should be avoided. Planter boxes offer considerable flexibility and can be incorporated into small spaces, enhancing natural aesthetics of the landscape.

Planter boxes are effective for removing

Treatment Efficiency			
Runoff Volume	Low	Metals	High
Sediment	High	Oil & Grease	High
Nutrients	Medium	Organics	High
Pathogens	High		



Siting and Suitability

Greenroofs are typically constructed on flat or gently sloped rooftops of a wide variety of shapes and sizes. Where installed on new construction, building structural design should consider the additional load of the greenroof. Where installed on existing buildings the structure should be evaluated by a structural engineer to determine suitability. Greenroofs can be implemented on a wide range of building types and settings and can integrate with other roof infrastructure such as HVAC components, walkways, and solar panels.

Drainage Area: Varies widely from a few square feet to several acres.

Aquifer Protection Zones and Karst: Not applicable. The use of greenroofs may reduce the need for downstream components to address these issues.

Head Requirements: Not applicable

Slopes: Green roofs can be installed on roof surfaces that are flat or are sloped.

Setbacks: Not applicable

Structural Requirements: a structural engineer should evaluate the structure to ensure that it is capable of supporting the greenroof.

Areas of Concern: In areas of significant wind loads design considerations may be necessary to ensure security of media or a greenroof may not be suitable.

Design Considerations & Specifications (see Appendix B for details)

Design Component		General Specification
BMP Function	1 Roof Slope	Greenroofs may be constructed on slopes from 1% to 30%. Where slopes approach 30% media retention practices such as baffles or geo-grids should be incorporated into the design.
	2 Waterproof Liner	All greenroof systems should incorporate a waterproof liner to protect the roof deck and underlying structure from leaks.
	3 Insulation (optional)	Insulation may be placed either above or below the waterproof liner to enhance the energy efficiency of the building and to provide additional protection of the roof deck.
	4 Root Barrier	Root barrier is placed directly above the waterproof liner, or insulation as appropriate, to prevent plant roots from impacting the integrity of the liner
	5 Drainage Layer	Aggregate: Minimum of 2 inches of clean washed synthetic or inorganic aggregate material such as no 8 stone or suitable alternatives. Manufactured: A wide range of prefabricated drainage layers are available which incorporate drainage and storage or rainfall. Minimum storage capacity should be 0.8 inches.
	6 Root Permeable Filter Fabric	A semipermeable filter fabric is placed between the drainage layer and growth media to prevent migration of the media into the drainage layer.
Growth Media	7 Media Depth	Minimum 4 inches of growth media.
	8 Media Composition	80–90% lightweight inorganic materials such as expanded slates, shales, or pumice. No more than 20% organic materials with a low potential for leaching nutrients.
Other Considerations	9 Roof Drains and Scuppers	Setback greenroof media and drainage layers a minimum of 12 inches from all roof drains and scupper and fill these areas with washed no. 57 stone to a depth equal to or greater than the depth of the greenroof components.
	10 Other Infrastructure	Separate greenroof 24 inches from other rooftop infrastructure such as vents, HVAC components, etc. Setback areas may be filled with washed no. 57 gravel or suitable alternative.
	11 Access	Adequate access to the roof must be provided to allow routine maintenance.
Landscape	12 Vegetation	Primarily drought tolerant species which can thrive in a rooftop environment without supplemental irrigation; see Plant List (Appendix E).
	13 Multi-Use Benefits	Include features to enhance habitat, aesthetics, recreation, and public education as desired.

Maintenance Considerations (see Appendix F for detailed checklist)

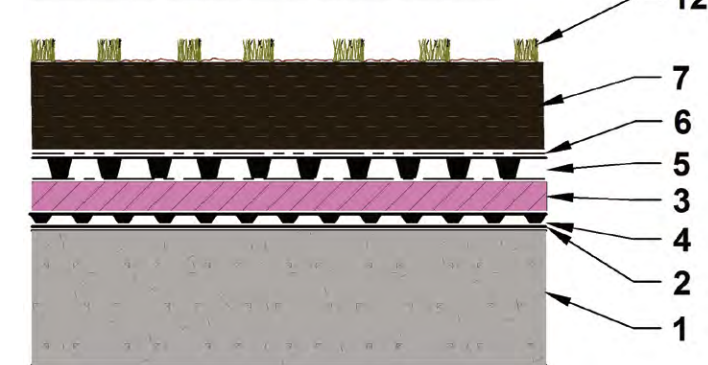
Task	Frequency	Indicator Maintenance is Needed	Maintenance Notes
Media Inspection	2 times/year	Internal erosion of media from runoff or wind scour, exposed underlayment components	Replace eroded media and vegetation. Adopt additional erosion prevention practices as appropriate.
Liner Inspection	1 time/year	Liner is exposed or tenants have experienced leaks	Evaluate liner for cause of leaks. Repair or replace as necessary.
Outlet Inspection	2 times/year	Accumulation of litter and debris around the roof drain or scupper or standing water in adjacent areas.	Litter, leaves, and debris should be removed to reduce the risk of outlet clogging. If sediment has accumulated in the gravel drain buffers remove and replaces the gravel.
Vegetation Inspection	1 time/year	Dead plants or excessive open areas on greenroof	Within the first year, 10 percent of plants can die. Survival rates increase with time.
Invasive Vegetation	2 times/year	Presence of unwanted or undesirable species	Remove undesired vegetation. Evaluate greenroof for signs of excessive water retention.
Temporary Watering	1 time/2–3 days for first 1–2 months	Until establishment and during severely-droughty weather	Watering after the initial year might be required.

Extensive Green Roof



A modular extensive green roof in Fallbrook, California, was installed on the roof of a public library. Prefabricated plastic trays were planted with colorful varieties of stonecrop.

Extensive Green Roof Cross Section



Typical components of an extensive green roof. The cross section of intensive green roofs will be deeper and vary from site to site based on desired functions and structural capacity of the underlying structure.

Description

Greenroofs are vegetated surfaces generally installed on flat or gently sloped rooftops. They consist of drought tolerant vegetation grown in a thin layer of media underlain by liner and drainage components. They reduce stormwater runoff volume and improve water quality by intercepting rainfall which is either filtered by the media, evaporated from the roof surface or utilized by the vegetation. Greenroofs can be installed on a wide range of building types and may provide additional functions such as extending roof-life and reducing energy requirements of the building. Research has shown that Greenroofs also may improve property values of adjacent buildings and provide air quality benefits. In addition to these functions greenroofs can serve as passive recreation areas and provide wildlife habitat.

Treatment Efficiency

	High	Bacteria	Medium
Runoff Volume	High	Bacteria	Medium
TSS	Medium	Nutrients	Medium
Trash/debris	Medium	Heavy Metals	High
Organics	Medium	Oil & Grease	NA



Siting and Suitability

Sand filters require less space than many LID BMPs and are typically used in areas with restricted space such as parking lots or other highly impervious areas. Sizing should be based on the desired water quality treatment volume the *Storm Water Design Standards Manual* specifications and should take into account all runoff at ultimate build-out, including off-site drainage. The design phase should also identify where pretreatment will be needed. Aboveground units should be designed with a vegetated filter strip or forebay as a pretreatment element, and belowground units should incorporate a forebay sediment chamber.

Aquifer Protection Zones and Karst: Sand filters can be used in sensitive geology if impermeable liners are used.

Underground Utilities: A complete utilities inventory should be done to ensure that site development will not interfere with or affect the utilities.

Existing Buildings: If used underground, ensure that the sand filter will not interfere with existing foundations.

Water Table and Bedrock: Sand filters are applicable where depth from subgrade to seasonal high water table, bedrock, or other restrictive feature is 3 ft or greater.

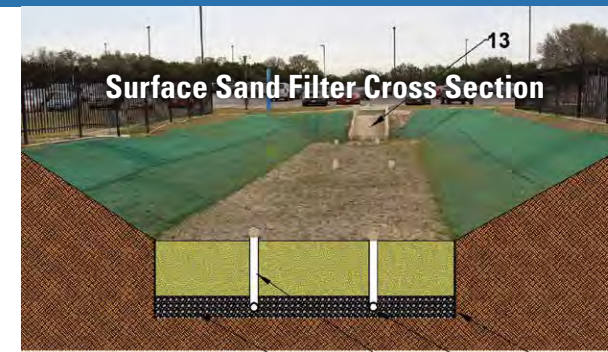
Soil Type: If infiltration is planned to existing soils, examine site compaction and soil characteristics. Determine site-specific permeability. It is ideal to have well-drained soils. If native soils show less than 0.5 in/hr infiltration rate, underdrains should be included.

Areas of Concern: Sand filters, if lined, can be used for sites with known soil contamination or *hot spots* such as gas stations. Impermeable membranes must be used to contain infiltration within areas of concern.

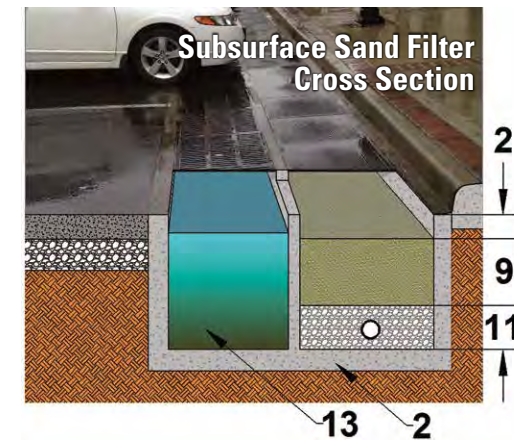
Design Considerations & Specifications

(see Appendix B for details)

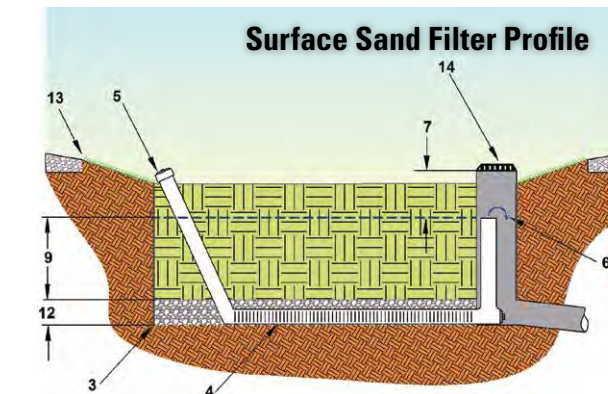
Design Component	General Specification
BMP Function	1 BMP Type Surface sand filters: installed in shallow depressions on surface. Require pretreatment by vegetated swales, filter strip, or forebay. Subsurface sand filters: can be installed along the edges of roads and parking lots to conserve space. Must include a sedimentation chamber for pretreatment.
	2 Impermeable liner If non-infiltrating (per geotechnical investigation), use clay liner, geomembrane liner, or concrete.
	3 Lateral hydraulic restriction barriers May use concrete or geomembrane to restrict lateral seepage to adjacent subgrades, foundations, or utilities.
	4 Underdrain/Infiltration Underdrain required if subsoil infiltration < 0.5 in/hr. Schedule 40 PVC pipe with perforations (slots or holes) every 6 inches. 4-inch diameter lateral pipes should join a 6-inch collector pipe. If design is fully infiltrating, ensure that subgrade compaction is minimized.
	5 Cleanouts/Observation Wells Provide cleanout ports/observation wells for each underdrain pipe at spacing consistent with local regulations.
	6 Internal Water Storage (IWS) If using underdrain in infiltrating systems, the underdrain outlet can be elevated to create a sump for enhanced infiltration and treatment. Top of IWS should be greater than 10 inches below surface.
	7 Temporary Ponding Depth No greater than 8 feet (shallower depth should be used in residential areas or near schools and parks).
	8 Drawdown Time Surface drawdown: 12–24 hrs.
Soil Media	9 Soil Media Depth 1.5–4 feet (deeper for better pollutant removal, hydrologic benefits, and deeper rooting depths).
	10 Gradation Washed concrete sand (ASTM C-33) free of fines, stones, and other debris.
	11 Chemical Analysis Total phosphorus < 15 ppm.
Routing	12 Drainage Layer Separate soil media from underdrain with 2 to 4 inches of washed concrete sand (ASTM C-33), followed by 2 inches of choking stone (ASTM No. 8) over a 1.5 ft envelope of ASTM No. 57 stone.
	13 Inlet/Pretreatment Provide stabilized inlets and energy dissipation. Install rock armored forebay for concentrated flows, gravel fringe and vegetated filter strip for sheet flows to surface sand filters. For subsurface sand filters, a sedimentation chamber is provided (should be dewatered between storm events).
Other	14 Outlet Configuration Online: All runoff is routed through system—install an elevated overflow structure or weir at the elevation of maximum ponding. Offline: Only treated volume is diverted to system—install a diversion structure or allow bypass of high flows.
	15 Multi-Use Benefits Provide features to enhance aesthetics and public education.



A surface sand filter captures and filters runoff diverted from a parking lot at the University of Texas at San Antonio.



A subsurface sand filter captures parking lot runoff in a sedimentation chamber for pretreatment. Flow then passes through slots in the divider wall into the sand filter chamber.



Maintenance Considerations (see Appendix F for detailed checklist)

Task	Frequency	Indicator Maintenance is Needed	Maintenance Notes
Catchment inspection	Weekly or biweekly with routine property maintenance	Excessive sediment, trash, and/or debris accumulation on the surface of sand filter.	Permanently stabilize any exposed soil and remove any accumulated sediment. Adjacent pervious areas may need to be regarded.
Inlet inspection	Once after first major rain of the season, then every 2 to 3 months depending on observed sediment and debris loads	Debris or sediment has blocked inlets.	Remove any accumulated material.
Sedimentation chamber/forebay inspection	Every two months	Sediment has reached 6-inches-deep (install a fixed vertical sediment depth marker) or litter and debris has clogged weirs between sedimentation chamber and sand filter chamber (for subsurface filters).	Remove accumulated material from sedimentation chamber. Remove and replace top 2 to 3 inches of sand filter if necessary.
Sand filter surface infiltration inspection	After major storm events or biannually	Surface ponding draws down in greater than 48 hours.	Remove and replace top 2 to 3 inches of sand filter, or as needed to restore infiltration capacity. Inspect watershed for sediment sources.
Outlet inspection	Once after first major rain of the season, then monthly	Erosion or sediment deposition at outlet.	Check for erosion at the outlet and remove any accumulated sediment.
Miscellaneous upkeep	12 times/year		Tasks include trash collection, spot weeding, soil media replacement, and removal of visual contamination.

Description

Sand filters are filtering BMPs that can be installed on the surface or subsurface. They remove pollutants by filtering stormwater vertically through a sand media and can also be designed for infiltration. Although they function similar to bioretention, sand filters lack the pollutant removal mechanisms provided by the biological activity and fine clay particles found in bioretention media.

Treatment Efficiency

Runoff Volume	Low
Sediment	High
Nutrients	Low
Pathogens	Medium
Metals	Low
Oil & Grease	Medium
Organics	Medium



Siting and Suitability

Stormwater wetlands are typically constructed in the lowest elevation of a site to convey runoff via gravity flow and to minimize excavation requirements. However, sufficient elevation gradient to the existing stormwater network is required to discharge effluent. Constructed wetlands can be incorporated along the perimeter of a site by designing a long, linear footprint, or can serve as an attractive amenity in common areas of developments. If the entire design volume cannot be stored in a single location or if utility conflicts are apparent, wetland pockets can be distributed between several locations and connected with vegetated channels and/or buried conduit. Most importantly, proper function of stormwater wetlands relies on the adequate supply of groundwater, baseflow, or runoff to maintain permanent pools during dry periods. Stormwater wetlands can provide additional site benefits, such as public/youth education and wildlife habitat, and be incorporated as part of open space plans across various land uses.

Drainage Area: A 10-acre minimum drainage area is recommended.

Aquifer Protection Zones and Karst: Use impermeable liner to protect subsurface resources and prevent sinkholes.

Head Requirements: Wetlands typically require a minimum of 3.0 ft of elevation difference.

Slopes: Interior side slopes above the shallow water zone should be 3:1 (H:V) or flatter. 2:1 side slopes are appropriate within the deep pool zones.

Setbacks: Provide 10-ft setback from structures/foundations, 100-ft setback from septic fields and water supply wells, and 50-ft setback from steep slopes.

Areas of Concern: Within residential, school, and other uncontrolled public areas, safety measures such as a protective perimeter fence should be considered.

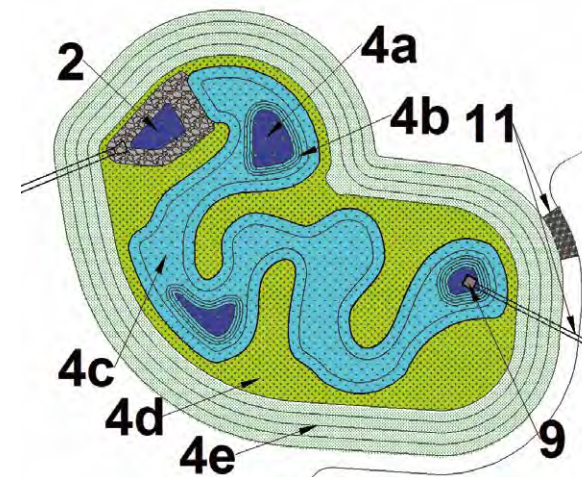
Design Considerations & Specifications (see Appendix B for details)

Design Component	General Specification
BMP Function	1 Water Balance: Evapotranspiration/Infiltration Rate of water loss during dry months should not exceed supply from groundwater, baseflow, or runoff to ensure water is maintained in permanent pools.
	2 Sediment Forebay Forebay should be 18- to 36-inches-deep, 10% of the temporary ponding surface area, and should be lined with riprap for energy dissipation.
	3 Maximum Flow Path The minimum length-to-width (L:W) ratio should be 2:1, but L:W should be maximized by creating a sinuous flow path and placing the outlet as far from the inlet as possible.
	4a Wetland Zones Deep Pools: 15–20% of wetland surface area (including forebay), 18- to 36-inches-deep.
	4b Transition: 10–15% of wetland surface area, transition between deep pool and shallow water, 12–18 inches deep, maximum slopes of 1.5:1.
	4c Shallow Water: 40% of wetland surface area, 3- to 6-inches-deep, flat or 6:1 slope (at least 6-foot radius around all deep pools to provide safety shelf).
4d Temporary Ponding: 30–40% of wetland surface area, up to 12-inches-deep, 3:1 slopes.	
4e Detention Storage/Upland: Additional ponding depth can be provided for peak flow mitigation, as needed, but depth should generally not exceed 4 feet above the permanent pool elevation.	
5 Temporary Ponding Depth Provide 6–12 inches temporary ponding above normal pool.	
6 Drawdown Time Drawdown orifice is designed to discharge the water quality volume in 2 to 5 days (longer times maximize treatment efficiency).	
Topsoil	7 Topsoil Depth 1–4 inches of topsoil should be applied to support plant growth. Depth depends on specified plantings and underlying soil characteristics.
	8 Topsoil Composition Natural, friable soil representative of productive, well-drained soils in the area. It shall be free of subsoil, stumps, rocks larger than 1-inch diameter, brush weeds, toxic substances, and other material detrimental to plant growth. Low phosphorus (TP < 15 ppm) with pH 5.5–7.
Routing	9 Outlet Configuration Online: All runoff is routed through the wetland basin—install an elevated riser structure or weir with an orifice at the permanent pool elevation and an overflow at the maximum temporary ponding elevation. Offline: Runoff in excess of the design water quality volume bypasses the wetland.
	10 Design Drawdown Orifice Non-clogging orifices should feature a downturned pipe that extends 6 to 12 inches below the permanent pool elevation in an area of open water (deep pool).
	11 Outfall Pipe and Emergency Overflow The outlet barrel should incorporate an anti-seepage device as appropriate to prevent lateral seepage, and discharge to an adequately stabilized area; an emergency spillway should be provided to safely bypass extreme flood flows.
	12 Maintenance/Emergency Dewatering Design A protected inlet should be provided near the base of the outlet structure with a tamper-proof manual valve (intake should be sized one standard pipe size larger than needed to dewater the basin in 24 hours).
Landscape	13 Vegetation Primarily annual and perennial wetland plants specified by zones.
	14 Multi-Use Benefits Include features to enhance habitat, aesthetics, recreation, and public education as desired.

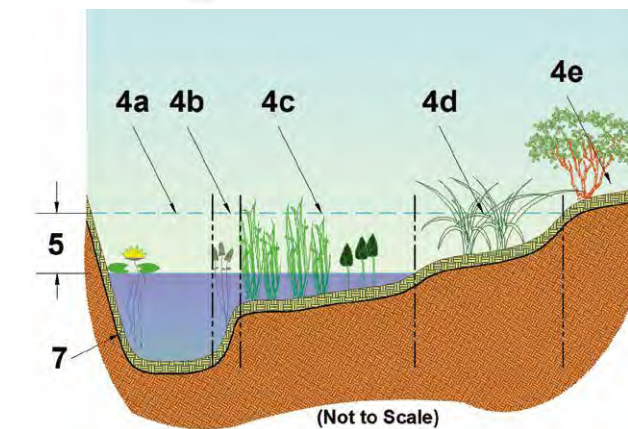
Maintenance Considerations (see Appendix F for detailed checklist)

Task	Frequency	Indicator Maintenance is Needed	Maintenance Notes
Forebay Inspection	Weekly or biweekly	Internal erosion or excessive sediment, trash, and/or debris accumulation	Check for sediment accumulation to ensure that forebay capacity is as designed. Remove any accumulated sediment.
Basin Inspection	1 time/year	Excessive sediment, trash, and/or debris accumulation in the wetland	Remove any accumulated sediment. Adjacent pervious areas may need to be re-graded.
Outlet Inspection	Weekly or biweekly with routine property maintenance	Accumulation of litter and debris within wetland area, large debris around outlet, internal erosion	Litter, leaves, and debris should be removed to reduce the risk of outlet clogging and to improve facility aesthetics. Erosion should be repaired and stabilized.
Mowing	2-12 times/year	Overgrown vegetation on embankment or adjacent areas	Frequency depends on location and desired aesthetic appeal.
Embankment Inspection	1 time/year	Erosion at embankment	Repair eroded areas and re-vegetate.
Remove and Replace Dead Vegetation	1 time/year	Dead plants or excessive open areas in wetland	Within the first year, 10 percent of plants can die. Survival rates increase with time.
Temporary Watering	1 time/2–3 days for first 1–2 months	Until establishment and during severely-droughty weather	Watering after the initial year might be required.

Typical Wetland Plan



Typical Stormwater Wetland Profile



Diverse wetland zones provide important water quality functions and ecosystem services. To enhance plant survival, vegetation should be carefully selected for the water depth and hydroperiod of each zone.

Description

Constructed stormwater wetlands are basins that retain a permanent body of shallow water that facilitates the growth of a range of dense wetland vegetation. Constructed to mimic the functions of natural wetlands, stormwater wetlands are a multi-functional, bio-diverse BMP that employ a range of pollutant removal mechanisms. Wetlands create a shallow matrix of sediment, plants, water, and detritus that collectively remove multiple pollutants through a series of complementary physical, chemical, and biological processes. Despite having a higher land requirement as compared to other detention-based BMPs, stormwater wetlands are one of the best practices for removing TSS, nitrogen, and phosphorus while also providing stormwater peak flow attenuation. In addition to their water quality function, stormwater wetlands can also improve site aesthetics and provide an excellent habitat for wildlife and waterfowl.

Treatment Efficiency

Runoff Volume	Low	Bacteria	High
TSS	High	Nutrients	Medium
Trash/debris	High	Heavy Metals	High
Organics	High	Oil & Grease	High



Siting and Suitability

Extended detention basins (EDBs) are typically constructed down gradient of disturbed and/or developed areas, in an area that will collect the most runoff from the sites impervious surfaces. Additional care should be given to avoid steep slopes and limit tree removal.

The primary design pollutant removal pathway is settling and EDBs, therefore, are most effective for removal of sediment and particle-associated pollutants. The effectiveness of the EDB is enhanced by designing with the appropriate dimensions, including a long flow path to prevent short circuiting, structures to reduce velocities, and avoiding stagnant pools.

EDBs are most often used in residential neighborhoods, commercial areas, and industrial sites, but can also be used for roads and parking lots.

Drainage Area: A 5-acre minimum drainage area is recommended.

Aquifer Protection Zones and Karst: Use impermeable liner to protect subsurface resources and prevent sinkholes.

Longitudinal Slope: A slope of 0.4% - 1% is required along the trickle or low flow channel.

Slopes: Interior side slopes should be 3:1 (H:V) or flatter.

Setbacks: Provide 10-ft setback from structures/foundations, 100-ft setback from septic fields and water supply wells, and 50-ft setback from steep slopes.

Areas of Concern: Within residential, school, and other uncontrolled public areas, safety measures such as a protective perimeter fence should be considered.

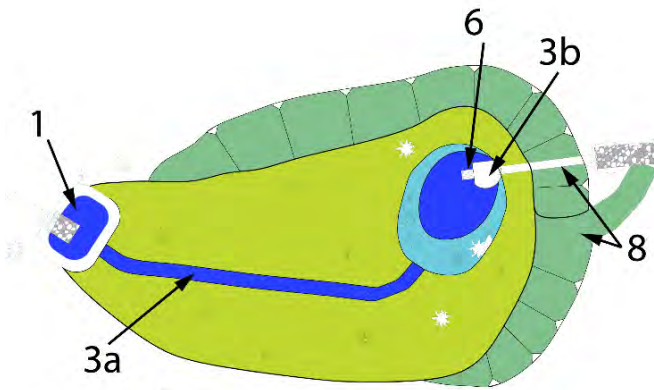
Design Considerations and Specifications (see Appendix B for details)

Design Component	General Specification
BMP Function	1 Sediment forebay Forebay volume should be sized to 10% of the water quality volume plus an additional 20% oversizing to account for sediment accumulation; should be 2 to 5 feet deep; incorporate sediment depth marker for measuring accumulation; energy dissipation should be used at the inlet area to prevent erosion or resuspension of sediment.
	2 Maximum flow path The minimum length to width (L:W) ratio must be at least 2:1, but L:W should be maximized by creating a sinuous flow path and placing the outlet as far from the inlet as possible. Baffles may also be considered.
	3a Basin Zones Trickle or Low Flow Channel: To convey flow from the forebay to the micropool, a concrete lined low flow channel or trickle channel is required; A concrete lined channel with slope between 0.4% - 1% and 9 inches deep is recommended.
	3b Micropool: 10% of treatment volume or 5% of the surface area of the water quality pool; the micropool should be located at the bottom active storage volume near the outfall; Slopes should be 3:1 with a minimum surface area of 10 square feet; micropools should not have a low flow pilot channel.
3c Detention Storage: Additional ponding depth can be provided for peak flow mitigation; the design storage volume should be based on the appropriate local requirements.	
Topsoil	4 Topsoil Depth 1–4 inches of topsoil should be applied to support plant growth. Depth depends on specified plantings and underlying soil characteristics.
	5 Topsoil Composition Natural, friable soil representative of productive, well-drained soils in the area. It shall be free of subsoil, stumps, rocks larger than 1-inch diameter, brush weeds, toxic substances, and other material detrimental to plant growth. Low phosphorus (TP < 15 ppm) with pH 5.5–7.
Routing	6 Outlet configuration The outlet should be designed as a riser with orifices to discharge the water quality volume over a 48 hour period. The basin must include the low-flow outlet to slowly release water, a primary outlet to release peak flows of larger design storms, and trash rack to prevent clogging of both outlets.
	7 Design drawdown orifice Non-clogging orifices sized to allow for complete drawdown of the water quality volume in 48 hours and no more than 50% of the water quality volume should drain from the facility within the first 24 hours.
	8 Outfall pipe and emergency overflow The hydraulic design of the outfall structure should consider tailwater effects from downstream waterways; an emergency spillway should be sized to safely pass the flow based on the appropriate local requirements for the flood control detention volume.
Landscape	9 Maintenance A protected inlet should be provided near the base of the outlet structure with a tamper-proof manual valve (intake should be sized one standard pipe size larger than needed to dewater the basin in 24 hours).
	11 Vegetation Basin bottom, berms, and side slopes should be planted with native or meadow grasses (See Appendix E - Plant List); a minimum 25-foot vegetative buffer should extend away from the top of the pond slope in all directions – woody vegetation should not be planted in this zone, but existing trees should remain.
12 Multi-use Benefit Include features to enhance habitat for beneficial pollinators, aesthetics, recreation, and public education as desired.	

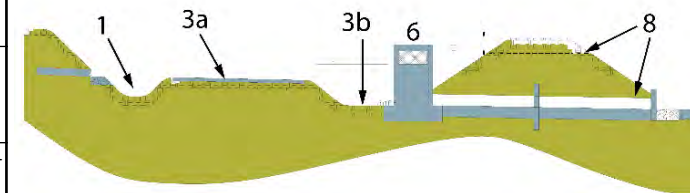
Maintenance Consideration (see Appendix F for detailed checklist)

Task	Frequency	Indicator maintenance is needed	Maintenance Notes
Forebay inspection	Weekly or biweekly	Internal erosion or excessive sediment, trash, or debris accumulation	Check for sediment accumulation to ensure that forebay capacity is as designed. Remove any accumulated sediment.
Basin inspection	1 time/year	Cracked, eroded, or broken structural components	Repair pond inlets, outlets, forebays, low flow channel liners, and energy dissipaters when damage is discovered
Outlet inspection	After major storm events	Accumulation of litter and debris in basin area, large debris around outlet, internal erosion	Remove litter, leaves, and debris to reduce the risk of outlet clogging Erosion should be repaired and stabilized.
Mowing	2 times/year	Overgrown vegetation on embankment or adjacent areas	Frequency depends on location and desired aesthetic appeal
Embankment inspection	1 time/year	Erosion at embankment	Repair eroded areas and revegetate.
Vegetation	1 time/year	Dead plants; Woody growth on embankments	Within the first year, 10% of plants can die. Survival rates increase with time. Remove trees that encroach embankment toe, top, and buffer area.
Temporary watering	1 time/2–3 days for first 1–2 months	Until establishment and in severe drought	Watering after the initial year might be required.
Nuisance control	Biweekly or as Needed	Animals, feces, or burrows evident in or around EDB; Excessive mosquitos; Odor.	Employ qualified wildlife management professionals if needed. Remove stagnant or standing water that create odor and mosquito habitat.
Fertilization	1 time initially	Upon planting	One-time spot fertilization for first year vegetation.

Typical EDB Plan



Typical EDB Profile



Description

Extended Detention Basins (EDBs) are detention or sedimentation basins that discharge the design water quality volume of stormwater runoff over an extended period, usually from 24 to 48 hours. These devices function similar to flood control / detention basins, but include the extended holding period to encourage settling of sediment and particulate matter, exposure to UV sunlight, and other processes that treat pollutants before discharge. Therefore, in addition to the water quality benefit, EDBs provide the additional benefit of mitigating flooding by reducing peak discharge of storm water runoff and providing additional flood detention storage. In addition, controlling runoff rates helps to protect the downstream receiving waters from erosion.

Treatment Efficiency

Runoff Volume	Moderate
Sediment	Medium
Bacteria	Medium
Trash/debris	High
Nutrients	Medium
Heavy Metals	Low
Oil & Grease	Low
Organics	Medium



Siting and Suitability

Cisterns should be placed near a roof downspout, but can also be located remotely if a “wet conveyance” configuration is used. The structural capacity of soils should be investigated to determine whether a footer is needed. Cisterns are available commercially in numerous sizes, shapes, and materials. The configuration will be determined by available space, intended reuse strategy, and aesthetic preference. An overflow mechanism is important to prevent water from backing up onto rooftops—overflow should be conveyed in a safe direction away from building foundations.

Drainage Area: Rooftop area.

Aquifer Protection Zones and Karst:

Harvested water may be used for irrigation only if irrigated area contains at least 12 inches of native soil. No runoff should result from irrigation.

Existing Buildings: Ideally, cistern overflows should be set away from building foundations at least 5 feet.

Water Table: The seasonal high water table should be located below the bottom of the cistern, particularly underground cisterns, to prevent buoyant forces from affecting the cistern.

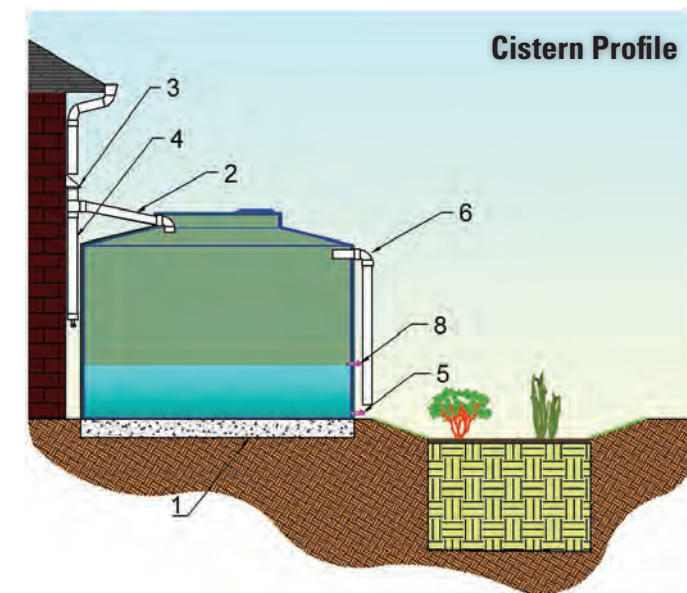
Soil Type: Ensure that the cistern is securely mounted on stable soils. If structural capacity of the site is in question, complete a geotechnical report to determine the structural capacity of soils.

Areas of Concern: Overflow volume or outflow volume should not be directed to areas where infiltration is not desired. Such areas may include *hot spots*, where soils can be contaminated.

Design Considerations & Specifications

(see Appendix B for details)

Design Component	General Specification
Configuration and Function	1 Cistern material and foundation Tanks should typically be opaque to prevent algal growth. A foundation of gravel should be provided if the weight of the cistern at capacity is less than 2000 pounds, otherwise a concrete foundation should be provided.
	2 Conveyance configuration Runoff should be conveyed to the cistern such that no backwater onto roofs occurs during the 100-yr event. Two types of inlet configurations are available: • Dry conveyance: conduit freely drains to cistern with no water storage in pipe • Wet conveyance: a bend in the conduit retains water between rainfall events (allows cistern to be placed further from buildings)
	3 Inlet filter A self-cleaning inlet filter should be provided to strain out large debris such as leaves. Some systems incorporate built-in bypass mechanisms to divert high flows.
	4 First flush diverter A passive first flush diverter should be incorporated in areas with high pollutant loads to capture the first washoff of sediment, debris, and pollen during a rainfall event. First flush diverters are typically manually dewatered between events.
	5 Low-flow outlet An outlet should be designed to dewater the water quality storage volume to a vegetated area in no less than 2 days. The elevation of the outlet depends on the volume of water stored for alternative purposes.
	6 Overflow or bypass Emergency overflow (set slightly below the inlet elevation) or bypass must be provided to route water safely out of the cistern when it reaches full capacity.
Reuse and Safety	7 Signage Signage indicating: “Caution: Reclaimed Water, Do Not Drink” (preferably in English and Spanish) must be provided anywhere cistern water is piped or outlets.
	8 Pipe color and locking features All pipes conveying harvested rainwater should be Pantone color #512 and be labeled as reclaimed water. All valves should feature locking features.
	9 Routing water for use Regardless of gravity or pumped flow, adequate measures must be taken to prevent contamination of drinking water supplies.
	10 Makeup water supply A makeup water supply can be provided to refill the cistern to a desired capacity when harvested water has a dedicated use.
	11 Vector control All inlets and outlets to the cistern must be covered with a 1-mm or smaller mesh to prevent mosquito entry/egress.
Other	12 Multi-use benefits Harvested rainwater should be used to offset potable water uses, such as irrigation, toilet flushing, car washing, etc. Additionally, educational signage and aesthetically-pleasing facades should be specified.



This schematic represents a water harvesting system with dry conveyance (water freely drains from the roof gutter to tank). Water from the low flow drawdown and the overflow are directed away from the building to an adjacent irrigation area.

Maintenance Considerations (see Appendix F for detailed checklist)

Task	Frequency	Indicator Maintenance is Needed	Maintenance Notes
Gutter and rooftop inspection	Biannually and before heavy rains	Inlet clogged with debris	Clean gutters and roof of debris that have accumulated, check for leaks
Remove accumulated debris	Monthly	Inlet clogged with debris	Clean debris screen to allow unobstructed stormwater flow into the cistern
Structure inspection	Biannually	Cistern leaning or soils slumping/eroding	Check cistern for stability, anchor system if necessary
Structure inspection	Annually	Leaks	Check pipe, valve connections, and backflow preventers for leaks
Add ballast	Before any major wind-related storms	Tank is less than half-full	Add water to half full
Miscellaneous upkeep	Annually		Make sure cistern manhole is accessible, operational, and secure

Description

Cisterns are storage vessels that can collect and store rooftop runoff from a downspout for later use. Sized according to rooftop area and desired volume, cisterns can be used to collect both residential and commercial building runoff. By temporarily storing the runoff, less runoff enters the storm water drainage system, thereby reducing the amount of pollutants discharged to surface waters. Additionally, cisterns and their smaller counterpart referred to as rain barrels are typically used in a treatment train system where collected runoff is slowly released into another BMP or landscaped area for infiltration. Because of the peak-flow reduction and storage for potential beneficial uses, subsequent treatment train BMPs can be reduced in size. Cisterns can collect and hold water for commercial uses, most often for non-potable uses such as irrigation or toilet flushing.

Treatment Efficiency

Runoff Volume	Varies based on cistern size and drawdown mechanisms
Water Quality	Water quality improvements depend on downstream practices—high pollutant removal can be achieved if paired with an infiltrating or filtering practice



Appendix E. Plant List

The following plant list was created to guide users of this manual in general selection of appropriate plants for the region. However, plant species commonly grown in landscape areas in San Antonio will grow differently in BMP applications, especially where amended or engineered soils are used. Please see the individual BMP design guidance in Appendix B before selecting plants. Plant selection and care is also dependent upon other factors such as microclimate, soil, rainfall, season, placement (e.g., north side of building), density, efficiency, and use. A knowledgeable landscape architect, horticulturalist, botanist, ecologist or arborist, preferably with experience in the San Antonio area, should be consulted for final plant selection. In addition, local tree preservation and landscaping regulations may limit the use of certain species. Detailed information about native plants is available from the Native Plant Information Network (NPIN) at <http://www.wildflower.org/explore/>. To find a plant's county-by-county distribution, please search the USDA's Plants Database at: <http://plants.usda.gov/>. To find native plant suppliers in your area, visit <http://www.wildflower.org/suppliers/>.

Common name	Scientific name	Native to SARB ¹	Size		Evergreen (E) Deciduous (D) or Semi	Lifespan / Duration (Annual [A], Perennial [P], Biennial [B])	Light			Soil Moisture				Comments	
			Height	Spread			Sun	Part sun/shade	Shade	Dry	Moist	Wet	Shallow water		
SHADE TREES															
American elm	<i>Ulmus americana</i>	✓	72'-90'	50'-70'	D	200+ yrs	✓	✓							
American sycamore	<i>Platanus occidentalis</i>	✓	75'-100'	50'-70'	D	200+ yrs	✓	✓	✓						
Arizona ash	<i>Fraxinus velutina</i>		36'-72'	45'-60'	D	30+ yrs	✓								Fast-growing
Bald cypress	<i>Taxodium distichum</i>	✓	50'-75'	30'-60'	D	600+ yrs	✓	✓							
Black walnut	<i>Juglans nigra</i>	✓	72'-100'	72'-100'	D	100+ yrs	✓	✓							Certain plants sensitive to tannins from walnut husks
Black willow	<i>Salix nigra</i>	✓	36'-72'	36'-72'	D	65+ yrs	✓	✓	✓						Fast-growing, stabilizes soil
Box elder	<i>Acer Negundo</i>	✓	35'-50'	30'-40'	D	75+ yrs	✓	✓							Fast-growing, susceptible to breakage
Bur oak	<i>Quercus macrocarpa</i>		36'-100'	36'-100'	D	200+ yrs	✓	✓	✓						
Monterrey Oak	<i>Quercus polymorpha</i>		36'-72'	20'-35'	S		✓	✓							
Cedar elm	<i>Ulmus crassifolia</i>	✓	50'-70'	40'-60'	D	100+ yrs		✓							Fast growing, long-living
Cottonwood	<i>Populus deltoides</i>	✓	12'-36'	12'-30'	D	100+ yrs	✓	✓	✓						Fast-growing, susceptible to breakage
Honey mesquite	<i>Prosopis glandulosa</i>	✓	12'-36'	12'-36'	D	75+ yrs	✓								Thorny, Attracts pollinators
Mexican sycamore	<i>Platanus mexicana</i>		40'-50'	30'-35'	D	70+ yrs	✓	✓							Benefits from occasional deep soakings
Montezuma cypress	<i>Taxodium mucronatum</i>		36'-72'	30'-60'	E	700+ yrs		✓							Deciduous in colder climates
Pecan	<i>Carya illinoensis</i>	✓	70'-100'	50'-70'	D	200+ yrs	✓								Edible fruit, prune to maintain strong branching

Common name	Scientific name	Native to SARB ¹	Size		Evergreen (E) Deciduous (D) or Semi	Lifespan / Duration (Annual [A], Perennial [P], Biennial [B])	Light			Soil Moisture				Comments	
			Height	Spread			Sun	Part sun/shade	Shade	Dry	Moist	Wet	Shallow water		
Sugarberry/ Hackberry	<i>Celtis laevigata</i>	✓	60'-80'	60'-70'	D	60+ yrs		✓							Bird Habitat
UNDERSTORY & SMALL TREES															
Anaqua	<i>Ehretia anacua</i>	✓	20'-45'	20'-45'	E	60+ yrs	✓	✓							Showy flowers & fruit, Attracts pollinators, birds
Guajillo	<i>Senegalia berlandieri</i>	✓	3'-15'	3'-15'	D	15+ yrs	✓	✓							Showy flowers, Attracts pollinators, birds
Huisache	<i>Vachellia farnesiana</i>	✓	15'-25'	15'-25'	D	30+ yrs	✓								Thorny, forms dense thickets through suckers, Attracts pollinators
Mexican buckeye	<i>Ungnadia speciosa</i>	✓	20'-30'	15'-20'	D	60+ yrs		✓							Seeds toxic if eaten
Mexican plum	<i>Prunus mexicana</i>	✓	15'-35'	15'-35'	D	25+ yrs	✓	✓							Attracts pollinators, birds, edible fruit
Red mulberry	<i>Morus rubra</i>	✓	12'-36'	10'-30'		50+ yrs	✓	✓	✓						Attracts birds, ripened fruit edible, toxic: leaves, stems, unripened fruit
Retama	<i>Parkinsonia aculeata</i>	✓	12'-36'	15'-40'	D	15+ yrs	✓								Thorny, self-seeds aggressively in moist soils, Attracts pollinators, birds
TX or Mexican redbud	<i>Cercis canadensis</i>	✓	10'-20'	10'-20'	D	20+ yrs	✓	✓							Showy flowers
Texas persimmon	<i>Diospyros texana</i>	✓	15'-35'	15'-35'	D, S	50+ yrs	✓	✓							Edible fruit, Attracts pollinators, birds

Common name	Scientific name	Native to SARB ¹	Size		Evergreen (E) Deciduous (D) or Semi	Lifespan / Duration (Annual [A], Perennial [P], Biennial [B])	Light			Soil Moisture				Comments	
			Height	Spread			Sun	Part sun/shade	Shade	Dry	Moist	Wet	Shallow water		
SHRUBS															
American beautyberry	<i>Callicarpa americana</i>	✓	3'-5'	3'-5'	D	P		✓							Showy berries, Attracts birds
Blackbrush acacia	<i>Vachellia rigidula</i>	✓	5'-15'	5'-15'	D	P	✓	✓							Thorny, suckers readily, often used for erosion control, Attracts pollinators
Buttonbush	<i>Cephalanthus occidentalis</i>	✓	6'-12'	6'-10'	D	P		✓	✓						Showy flowers, Attracts pollinators
Chile pequin	<i>Capsicum annuum</i>	✓	1'-2'	1'-2'	D	P	✓	✓	✓						Edible fruit (hot pepper), Attracts birds
Common elderberry	<i>Sambucus nigra ssp. Canadensis</i>	✓	6'-12'	6'-12'	D	P		✓							Showy flowers & fruit, Attracts pollinators, birds, ripened fruit edible, toxic parts: leaves, stems, unripened fruit
Dwarf palmetto	<i>Sabal minor</i>	✓	5'-10'	5'-10'	E	P	✓	✓	✓						Showy fruits
False willow	<i>Baccharis neglecta</i>	✓	6'-12'	6'-12'	S	P		✓							Attracts Pollinators
Illinois bundleflower	<i>Desmanthus illinoensis</i>	✓	2'-3'	1'-2'	D	P	✓								Attracts pollinators
Indigo spires salvia	<i>Salvia 'Indigo Spires'</i>		3.5'	3.5'	D	P	✓								Showy flowers
Narrow-leaf water primrose	<i>Ludwigia octovalvis</i>	✓	3'-6'	2'-4'	D	P	✓	✓							Fast-growing, reseeds readily
River fern	<i>Thelypteris kunthii</i>	✓	2.5'	1'	E	P		✓	✓						

Common name	Scientific name	Native to SARB ¹	Size		Evergreen (E) Deciduous (D) or Semi	Lifespan / Duration (Annual [A], Perennial [P], Biennial [B])	Light			Soil Moisture			Comments	
			Height	Spread			Sun	Part sun/shade	Shade	Dry	Moist	Wet		Shallow water
Rock rose	<i>Pavonia lasiopetala</i>	✓	4'	4'	D	P	✓	✓						Showy flowers, Attracts pollinators
Texas lantana	<i>Lantana urticoides</i> (<i>L. horrida</i>)	✓	2'-6'	2'-6'	E	P	✓	✓						Showy flowers, Attracts pollinators , stems become thorny with age
Texas sage	<i>Leucophyllum frutescens</i>	✓	2'-8'	2'-8'	E	P	✓	✓						Showy flowers, pollinators
Texas star hibiscus	<i>Hibiscus coccineus</i>		3'-6'	3'-6'	D	P	✓							Showy flowers
Turk's cap	<i>Malva viscus arboreus</i> var. <i>drummondii</i>	✓	3'-5'	3'-5'	E	P		✓	✓					Showy flowers & fruits, Attracts pollinators
GRASSES & GRASS-LIKE FORBS														
Big bluestem	<i>Andropogon gerardii</i>	✓	4'-8'	1'-3'	E*	P	✓	✓						Bunchgrass, droops with high soil moisture
Buffalograss	<i>Bouteloua dactyloides</i>	✓	6"-12"	spreads	S	P	✓							Spreads by rhizomes
Bushy bluestem	<i>Andropogon glomeratus</i>	✓	2'-5'	spreads	E*	P	✓							Showy seedheads
Canada wildrye	<i>Elymus canadensis</i>	✓	2'-4'	spreads	E*	P	✓	✓						Showy seedheads , establishes quickly
Cane bluestem	<i>Bothriochloa barbinodis</i>	✓	1'-3'	spreads	E*	P	✓							
Eastern gamagrass	<i>Tripsacum dactyloides</i>	✓	3'-6'	3'-4'	E	P		✓						Soil stabilizer

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			Height	Spread			Sun	Part sun/shade	Shade	Dry	Moist	Wet	Shallow water		
Fringed windmillgrass	<i>Chloris ciliata</i>	✓	1'-3'	spreads	E*	P		✓							
Green sprangletop	<i>Leptochloa dubia</i>	✓	2'-3'	spreads	E*	P	✓	✓							
Gulf Coast muhly	<i>Muhlenbergia capillaris</i>	✓	1.5'-3'	1.5'-3'	E*	P	✓								Showy seedheads
Hairy grama	<i>Bouteloua hirsuta</i>	✓	6"-18"	spreads	E*	P		✓							
Hooded windmillgrass	<i>Chloris cucullata</i>	✓	6"-24"	spreads	E*	P		✓							
Indiangrass	<i>Sorghastrum nutans</i>	✓	3'-6'	1'-3'	E*	P	✓	✓							Showy seedheads
Inland sea oats	<i>Chasmanthium latifolium</i>	✓	2'-4'	spreads	E*	P		✓	✓						Showy seedheads , spreads aggressively, erosion control
Horsetail (Scouring rush)	<i>Equisetum hyemale var. affine</i>	✓	2'-4'	spreads	E	P	✓	✓							Spreads aggressively
Lindheimer's muhly	<i>Muhlenbergia lindheimeri</i>	✓	2'-5'	2'-5'	E	P	✓								Semi-evergreen
Liriope	<i>Liriope muscari 'Big Blue'</i>		12"-18"	12"-18"	E	P		✓	✓						
Little bluestem	<i>Schizachyrium scoparium</i>	✓	1.5'-2'	spreads	E*	P	✓	✓							Showy Seedheads
Needle spikerush	<i>Eleocharis acicularis</i>	✓	6"	spreads	E*	A	✓								
Plains bristlegrass	<i>Setaria leucopila</i>	✓	3'-6'	spreads	E*	P	✓								
Purple threeawn	<i>Aristida purpurea</i>	✓	12"-18"	spreads	E*	A	✓								Good for erosion control
Purpletop	<i>Tridens flavus</i>	✓	2'-6'	spreads	E*	P	✓	✓							
Sand lovegrass	<i>Eragrostis trichodes</i>	✓	1'-3'	spreads	E*	P		✓							Adapts to heavier soils

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			Height	Spread			Sun	Part sun/shade	Shade	Dry	Moist	Wet	Shallow water		
Seep muhly	<i>Muhlenbergia reverchonii</i>	✓	1'-3.5'	1'-3.5'	E	P	✓								
Sideoats grama	<i>Bouteloua curtipendula</i>	✓	1'-3'	spreads	E*	P	✓	✓							Showy Seedheads , state grass of Texas
Slender spikerush	<i>Eleocharis tenuis</i>	✓	1'-3'	spreads	E*	P	✓								
Softstem bulrush	<i>Schoenoplectus/Scirpus tabernaemontani</i>	✓	3'-6'	spreads	E*	P	✓								Good for habitat reconstruction
Squarestem spikerush	<i>Eleocharis quadrangulata</i>	✓	1.5'-4'	spreads	E*	P	✓								
Switchgrass	<i>Panicum virgatum</i>	✓	3'-6'	3'-5'	E*	P	✓	✓							Showy Seedheads, soil stabilizer
Texas cupgrass	<i>Eriochloa sericea</i>	✓	1'-2'	1'-2'	E*	P	✓	✓							Attracts birds
Texas grama	<i>Bouteloua rigidiseta</i>	✓	6"-12"	spreads	E*	P	✓								
Vine mesquite	<i>Panicum obtusum</i>	✓	1'-2'	spreads	E*	P		✓							
Western wheatgrass	<i>Pascopyrum smithii</i>	✓	1'-2.5'	spreads	E*	P	✓	✓							Turf grass, can crowd out other grasses
VINES															
Alamo vine	<i>Merremia dissecta</i>	✓	6'-12'	4'-10'	D	P	✓	✓							Showy flowers, twining climber, can be aggressive
Carolina snailseed	<i>Cocculus carolinus</i>	✓	3'-15'	3'-15'	D	P		✓							Showy fruits, spreads vigorously, fast-growing
Mustang grape	<i>Vitis mustangensis</i>	✓	36'-72'	36'-72'	D	P		✓							Twining climber, showy fruit, edible fruit, Attracts birds

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			Height	Spread			Sun	Part sun/shade	Shade	Dry	Moist	Wet		Shallow water
Old man's beard	<i>Clematis drummondii</i>	✓	20'-25'	3'-6'	D	P	✓	✓						Showy seedheads, aggressive
Passionflower	<i>Passiflora foetida</i> v. <i>hirsuta</i>	✓	15'-20'	3'-6'	D	A	✓	✓						Twining climber, edible fruit, suckers vigorously
Peppervine	<i>Ampelopsis arborea</i>	✓	30'-40'	30'-40'	S	P	✓	✓						Showy fruits, aggressive, climbing and/or trailing
Trumpet creeper	<i>Campsis Radicans</i>	✓	25'-35'	6'-8'	D	P	✓							Showy flowers, climbs by aerial rootlets, aggressive
Virginia creeper	<i>Parthenocissus quinquefolia</i>	✓	12'-36'	12'-36'	D	P	✓	✓	✓					Fall color, high climbing or trailing with tendrils, toxic berries
SMALL FORBS & GROUNDCOVER														
American basketflower	<i>Centaurea americana</i>	✓	2'-5'	2'-5'	D	A	✓							Showy flowers, pollinators
American water-willow	<i>Justicia americana</i>	✓	1'-3'	1'-3'	D	P	✓	✓	✓					
Annual sunflower	<i>Helianthus annuus</i>	✓	2'-8'	1'-2'	D	A	✓	✓						Showy flowers, Attracts pollinators, birds, spreads rapidly by seed
Autumn sage (salvia)	<i>Salvia gregii</i>	✓	2.5'	2.5'	E	P	✓							Showy flowers, Attracts pollinators, stems brittle -
Bee blossom	<i>Gaura suffulta</i>	✓	1'-3'	1'-2'	D	A	✓							Showy flowers, Attracts pollinators
Black-eyed Susan	<i>Rudbeckia hirta</i>	✓	1'-3'	1.5'-2'	D	A	✓	✓						Showy flowers, Attracts pollinators

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			Height	Spread			Sun	Part sun/shade	Shade	Dry	Moist	Wet	Shallow water	
Blackfoot daisy	<i>Melampodium leucanthum</i>	✓	6"-12"	1'-2'	D	P	✓	✓						Showy flowers, Attracts pollinators
Blue curls	<i>Phacelia congesta</i>	✓	1'-3'	2'-3'	D	A	✓	✓	✓					Showy flowers, Attracts pollinators , best if sheltered from west sun, stem is brittle
Bulbine	<i>Bulbine frutescens</i>		1'-2'	2'-3'	E	P	✓	✓						
Bush sunflower	<i>Simsia calva</i>	✓	1'-3'	1'-3'	D	P	✓							
Butterflyweed	<i>Asclepias tuberosa</i>	✓	1'-2'	1'-2'	D	P	✓	✓						Showy flowers, Attracts pollinators, roots and plant sap are toxic
Clasping leaf coneflower	<i>Dracopis amplexicaulis</i>	✓	1'-2'	1'-2'	D	A	✓	✓						Showy flowers, Attracts pollinators
Cowpen daisy	<i>Verbesina encelioides</i>	✓	1'-3'	1'-2'	D	A	✓							Showy flowers, Attracts pollinators
Delta arrowhead	<i>Sagittaria platyphylla</i>	✓	1'-3'	1'-3'	D	P	✓	✓						
Drummond phlox	<i>Phlox drummondii</i>	✓	6"-18"	6"-18"	D	A	✓	✓						Showy flowers, Attracts pollinators
Drummond's woodsorrel	<i>Oxalis drummondii</i>	✓	6"-12"	6"-12"	D	P	✓	✓						Showy flowers, Attracts pollinators
Engelmann's daisy	<i>Engelmannia peristenia</i>	✓	1.5'-2'	1'-3'	E	P		✓	✓					Showy flowers, Attracts pollinators
Foxglove	<i>Penstemon cobaea</i>	✓	1'-2'	1'-2'	D	P	✓	✓						Showy flowers, Attracts pollinators , may go dormant during summer

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			Height	Spread			Sun	Part sun/shade	Shade	Dry	Moist	Wet	Shallow water	
Frogfruit	<i>Phyla nodiflora</i>	✓	3"-6"	3"-6"	S	P	✓	✓	✓					Attracts pollinators, tolerates drought and flooding
Gayfeather	<i>Liatriis mucronata</i>	✓	1'-3'	1'-2'	D	P	✓	✓						Showy flowers, Attracts pollinators
Golden wave	<i>Coreopsis basilis</i>	✓	6"-18"	6"-18"	D	A	✓	✓						Showy flowers, Attracts pollinators
Greenthread	<i>Thelesperma filifolium</i>	✓	1'-3'	1'-2'	D	A	✓							Showy flowers, Attracts pollinators
Hill Country rain lily	<i>Cooperia pedunculata</i>	✓	6"-12"	3"-6"	D	P	✓							Blooms after rain
Horsemint	<i>Monarda citriodora</i>	✓	1'-2'	1'-2'	D	A	✓	✓						Showy flowers, Attracts pollinators
Huisache daisy	<i>Amblyolepis setigera</i>	✓	6"-15"	6"-15"	D	A	✓	✓						Showy flowers, Attracts pollinators
Indian blanket	<i>Gaillardia pulchella</i>	✓	12"-18"	12"-18"	D	A	✓	✓						Showy flowers, Attracts pollinators
Indian paintbrush	<i>Castilleja indivisa</i>	✓	6"-16"	6"-9"	D	A	✓							Showy flowers, Attracts pollinators
Lanceleaf coreopsis	<i>Coreopsis lanceolata</i>		1'-2.5'	1'-2'	E	P	✓	✓	✓					Showy flowers, Attracts pollinators not reliably perennial, but self-sows readily
Lindheimers senna	<i>Senna lindheimeriana</i>	✓	1'-3'	3'-6'	D	P	✓	✓						Showy flowers, Attracts pollinators

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			Height	Spread			Sun	Part sun/shade	Shade	Dry	Moist	Wet		Shallow water
Maximilian sunflower	<i>Helianthus maximiliani</i>	✓	4'-6'	3'-6'	D	P	✓	✓						Showy flowers, pollinators, soil stabilizer
Mealy blue sage	<i>Salvia farinacea</i>	✓	2'-3'	1'-2'	D	P	✓	✓						Showy flowers, Attracts pollinators, birds
Mexican hat	<i>Ratibida columnifera</i>	✓	1'-3'	1'-2'	D	P	✓	✓						Showy flowers, Attracts pollinators Can be aggressive
Money plant, water pennywort	<i>Hydrocotyle umbellata</i>		3"-10"	3"-10"	D	P	✓	✓	✓					Can absorb pollutants
Obedient plant	<i>Physostegia intermedia</i>	✓	1'-5'	1'-3'	D	P	✓	✓	✓					Showy flowers, Attracts pollinators
Partridge pea	<i>Cassia/Chamaecrista fasciculata</i>	✓	1'-3'	1'-3'	D	A	✓	✓						Showy flowers, Attracts pollinators
Pickernelweed	<i>Pontederia cordata</i>	✓	3'-4'	2'-3'		P	✓	✓						Showy flowers, Attracts pollinators
Pigeonberry	<i>Rivina humilis</i>	✓	6"-18"	2'-3'	D	P		✓						Showy flowers & fruits toxic if ingested
Pink evening primrose	<i>Oenothera speciosa</i>	✓	1'-2'	1'-2'	S	P	✓	✓						Showy flowers, Attracts pollinators
Pitcher sage	<i>Salvia azurea</i>	✓	2'-4'	1'-3'	D	P	✓	✓						Showy flowers, Attracts pollinators
Plains coreopsis	<i>Coreopsis tinctoria</i>	✓	1'-2'	6"-12"	D	A	✓	✓						Showy flowers, Attracts pollinators
Prairie verbena	<i>Glandularia bipinnatifida</i>	✓	6"-12"	6"-12"	D	P	✓	✓						Showy flowers, Attracts pollinators

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			Height	Spread			Sun	Part sun/shade	Shade	Dry	Moist	Wet	
Purple coneflower	<i>Echinacea purpurea</i>		2'-4'	2'-4'	D	P	✓	✓					Showy flowers, Attracts pollinators
Zigzag Iris	<i>Iris brevicaulis</i>		1'-2'	1'-2'	D	P		✓	✓				Showy flowers
Purple prairie clover	<i>Dalea purpurea</i>	✓	1'-3'	1'-2'	D	P	✓						Showy flowers, Attracts pollinators
River primrose	<i>Oenothera jamesii</i>	✓	3'-6'	3'-6'	D	B	✓						Showy flowers, Attracts pollinators
Scarlet sage	<i>Salvia coccinea</i>	✓	6"-24"	6"-24"	S	P	✓	✓					Showy flowers, Attracts pollinators
Scrambled eggs	<i>Corydalis aurea</i>		6"-12"	9"-24"	D	A	✓						Showy flowers
Standing cypress	<i>Ipomopsis rubra</i>	✓	2'-4'	1'-2'	D	B	✓	✓					Showy flowers, pollinators, birds
Straggler daisy	<i>Calyptocarpus vialis</i>	✓	6"-12"	2'-3'	S	P	✓	✓	✓				Pollinators
Texas betony	<i>Stachys coccinea</i>		2.5'	2.5'	D	P		✓					Showy flowers, Attracts pollinators
Texas bluebonnet	<i>Lupinus texensis</i>	✓	6"-18"	6"-18"	D	A	✓						Showy flowers, pollinators, state flower of Texas
Texas vervain	<i>Verbena halei</i>	✓	1'-3'	15"	D	P	✓						Showy flowers, Attracts pollinators
Water hyssop	<i>Bacopa monnieri</i>	✓	6"-12"	6"-12"	D	P	✓	✓					
White gaura	<i>Oenothera lindheimeri</i>		2'-5'	1'-3'	D	P	✓	✓					Showy flowers, Attracts pollinators
White prairie clover	<i>Dalea candida</i>	✓	1'-2'	1'-2'	D	P	✓						

Common name	Scientific name	Native to SARB ¹	Size		Evergreen (E) Deciduous (D) or Semi	Lifespan / Duration (Annual [A], Perennial [P], Biennial [B])	Light			Soil Moisture				Comments	
			Height	Spread			Sun	Part sun/shade	Shade	Dry	Moist	Wet	Shallow water		
White pricklypoppy	<i>Argemone albiflora</i>	✓	2'-4'	2'-4'	D	A	✓	✓							Showy flowers, Attracts pollinators toxic foliage, can absorb pollutants
Widow's tears	<i>Commelina erecta</i>	✓	6"-18"	6"-18"	D	P		✓							
Wild petunia	<i>Ruellia nudiflora</i>	✓	1'-2'	1'-2'	D	P	✓	✓	✓						
Winecup	<i>Callirhoe involucrata</i>	✓	6"-12"	1'-2'	S	P	✓	✓							Showy flowers, Attracts pollinators

*Year-round leaf retention, but foliage loses color during dormancy

¹ Designates species native to the San Antonio River Basin (SARB). All other species listed are native to at least one region in the State of Texas except: Mexican sycamore, Indigo spires salvia, Bulbine, and Liriope.

Appendix F. Inspection and Maintenance Checklist

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	Property Owner _____
	Treatment Measure No. _____ Inspection Date _____
	Inspector(s) _____
	Type of Inspection:
	<input type="checkbox"/> Monthly <input type="checkbox"/> Pre-wet season <input type="checkbox"/> Post-wet season _____ <input type="checkbox"/> After heavy runoff <input type="checkbox"/> Other: _____

Defect	Conditions when maintenance is needed	Maintenance needed?	Comments ^a	Results expected when maintenance is performed
1. Standing water	Water stands in the bioretention area between storms and does not drain within 24 hours after rainfall.			There should be no areas of standing water once inflow has ceased. Any of the following could apply: sediment or trash blockages removed, grade from head to foot of bioretention area improved, media surface scarified, underdrains flushed.
2. Trash and debris	Trash and debris accumulated in the bioretention area and around the inlet and outlet.			Trash and debris removed from the bioretention area and disposed of properly.
3. Sediment	Evidence of accumulated sediment in the bioretention area.			Material removed so that there is no clogging or blockage. Material is disposed of properly.
4. Erosion	Channels have formed around inlets, there are areas of bare soil, or there is other evidence of erosion.			Obstructions and sediment removed so that water flows freely and disperses over a wide area. Obstructions and sediment are disposed of properly.
5. Vegetation	Vegetation is dead, diseased or overgrown.			Vegetation is healthy and attractive. Grass is maintained at least 3 inches in height.
6. Mulch	Mulch is missing or patchy. Areas of bare earth are exposed or mulch layer is less than 3 inches deep.			All bare earth is covered, except mulch is kept 6 inches away from trunks of trees and shrubs. Mulch is even at a depth of 3 inches.
7. Inlet/outlet	Sediment accumulations.			Inlet/outlet is clear of sediment and debris and allows water to flow freely.
8. Miscellaneous	Any condition not covered above that needs attention for the bioretention area to function as designed.			The design specifications are met.

^a Describe the maintenance completed; if the needed maintenance was not conducted, note when it will be done.

<h2 style="margin: 0;">Inspection and Maintenance Checklist</h2> <h3 style="margin: 0;">BIOSWALE</h3>	Property Address _____
	Property Owner _____
	Treatment Measure No. _____ Inspection Date _____
	Inspector(s) _____
	Type of Inspection:
	<input type="checkbox"/> Monthly <input type="checkbox"/> Pre-wet season <input type="checkbox"/> Post-wet season _____ <input type="checkbox"/> After heavy runoff <input type="checkbox"/> Other: _____

Defect	Conditions when maintenance is needed	Maintenance needed?	Comments ^a	Results expected when maintenance is performed
1. Standing water	Water stands in the bioswale between storms and does not drain within 24 hours after rainfall.			There should be no areas of standing water once inflow has ceased. Any of the following could apply: sediment or trash blockages removed, grade from head to foot of bioretention area improved, media surface scarified, underdrains flushed.
2. Trash and debris	Trash and debris accumulated in the bioswale and around the inlet and outlet.			Trash and debris removed from the bioswale and disposed of properly.
3. Sediment	Evidence of accumulated sediment in the bioswale.			Material removed so that there is no clogging or blockage. Material is disposed of properly.
4. Erosion	Channels have formed around inlets, there are areas of bare soil, or there is other evidence of erosion.			Obstructions and sediment removed so that water flows freely and disperses throughout the bioswale. Obstructions and sediment are disposed of properly.
5. Vegetation	Vegetation is dead, diseased, or overgrown.			Vegetation is healthy and attractive. Grass is maintained at least 3 inches in height.
6. Mulch (if used)	Mulch is missing or patchy. Areas of bare earth are exposed or mulch layer is less than 3 inches deep.			All bare earth is covered, except mulch is kept 6 inches away from trunks of trees and shrubs. Mulch is even at a depth of 3 inches.
7. Inlet/outlet	Sediment or debris accumulations.			Inlet/outlet is clear of sediment and debris and allows water to flow freely.
8. Miscellaneous	Any condition not covered above that needs attention for the bioswale to function as designed.			The design specifications are met.

^a Describe the maintenance completed; if the needed maintenance was not conducted, note when it will be done

<h2 style="margin: 0;">Inspection and Maintenance Checklist</h2> <h3 style="margin: 0;">PERMEABLE PAVEMENT</h3>	Property Address _____
	Property Owner _____
	Treatment Measure No. _____ Inspection Date _____
	Inspector(s) _____
	Type of Inspection:
	<input type="checkbox"/> Monthly <input type="checkbox"/> Pre-wet season <input type="checkbox"/> Post-wet season _____ <input type="checkbox"/> After heavy runoff <input type="checkbox"/> Other: _____

Defect	Conditions when maintenance is needed	Maintenance needed?	Comments ^a	Results expected when maintenance is performed
1. Standing water	When water stands on the surface of the permeable pavement and 48 hours has passed since the last rainfall.			There should be no areas of ponded/standing water more than 48 hours after a rain event. Any of the following can apply: surface swept or vacuumed, underdrains added, underdrains cleaned.
2. Trash and debris	Leaves, grass clippings, trash, etc., are preventing water from draining into the permeable pavement and are unsightly.			Area is free of all debris and the permeable pavement is draining properly.
3. Vegetation	Vegetation around the perimeter of the permeable pavement is dead, diseased, or overgrown. Weeds are growing on the surface of the permeable pavement.			Area adjacent to pavement is well-maintained and no bare/exposed areas exist; grass is maintained at a height of 3–6 inches. No weeds present in the pavement area.
4. Deteriorating surface	The pavement is cracked; paver blocks are misaligned or have settled.			The surface area is stabilized, exhibiting no signs of cracks or uneven areas in the pavement area.
5. Miscellaneous	Any condition not covered above that needs attention for the permeable pavement area to function as designed.			The design specifications are met.

^a Describe the maintenance completed; if the needed maintenance was not conducted, note when it will be done

<h2 style="margin: 0;">Inspection and Maintenance Checklist</h2> <h3 style="margin: 0;">PLANTER BOX</h3>	Property Address _____
	Property Owner _____
	Treatment Measure No. _____ Inspection Date _____
	Inspector(s) _____
	Type of Inspection: <input type="checkbox"/> Monthly <input type="checkbox"/> Pre-wet season <input type="checkbox"/> Post-wet season _____ <input type="checkbox"/> After heavy runoff <input type="checkbox"/> Other: _____

Defect	Conditions when maintenance is needed	Maintenance needed?	Comments ^a	Results expected when maintenance is performed
1. Standing water	When water stands in the planter box between storms and does not drain within 24 hours after rainfall.			There should be no areas of standing water after inflow has ceased. Any of the following could apply: sediment or trash blockages removed, mulch replaced, soil media surface scarified, underdrains flushed.
2. Trash and debris	Trash and debris accumulated in the planter box and around the inlet and outlet.			Trash and debris removed and disposed of properly.
3. Sediment	Evidence of accumulated sediment in the planter box.			Material removed so that there is no clogging or blockage. Material is disposed of properly.
4. Erosion	Channels have formed around inlets, there are areas of bare soil, or there is other evidence of erosion.			Obstructions and sediment removed so that water flows freely and disperses over a wide area. Obstructions and sediment are disposed of properly.
5. Vegetation	Vegetation is dead, diseased, or overgrown.			Vegetation is healthy and attractive. Grass maintained at least 3 inches in height.
6. Mulch	Mulch is missing or patchy; areas of bare earth are exposed, or mulch layer is less than 3 inches deep.			All bare earth is covered, except mulch is kept 6 inches away from trunks of trees and shrubs. Mulch is even at a depth of 3 inches.
7. Inlet/outlet	Sediment or debris accumulations.			Inlet/outlet is clear of sediment and debris and allows water to flow freely.
8. Affected impervious areas or structures	Obvious effects on surrounding impervious areas or structures.			Hydraulic restriction layers prevent impacts from infiltration to surrounding structures.
9. Miscellaneous	Any condition not covered above that needs attention for the planter box to function as designed.			The design specifications are met.

^a Describe the maintenance completed; if the needed maintenance was not conducted, note when it will be done.

<h2 style="margin: 0;">Inspection and Maintenance Checklist</h2> <h3 style="margin: 0;">GREEN ROOF</h3>	Property Address _____
	Property Owner _____
	Treatment Measure No. _____ Inspection Date _____
	Inspector(s) _____
	Type of Inspection: <input type="checkbox"/> Monthly <input type="checkbox"/> Pre-wet season <input type="checkbox"/> Post-wet season _____ <input type="checkbox"/> After heavy runoff <input type="checkbox"/> Other: _____

Defect	Conditions when maintenance is needed	Maintenance needed?	Comments ^a	Results expected when maintenance is performed
1. Standing water	Roof drainage system is clogged.			There should be no areas of standing water on the green roof. The drainage system is inspected for clogging conditions and repaired or replaced as needed.
2. Erosion	Areas of scoured media or bare roof.			Green roof media stays in place and does not migrate across or erode from roof surface. Eroded media replaced and re-vegetated. If problem is recurrent, consider media more resistant to wind erosion or installing media retention components.
3. Vegetation	Vegetation is dead, missing, incorrect or unwanted.			Areas of missing vegetation replanted. Plant species are appropriate to conditions and drainage system is functioning properly. If problem is recurrent, consider irrigation during establishment or use alternative species. Unwanted vegetation removed and replaced with appropriate species. Evaluate growing conditions for cause of invasive vegetation.
4. Leaking roof	Roof liner has failed.			Evaluate liner for cause of leaks. Repair or replace as necessary.

^a Describe the maintenance completed; if the needed maintenance was not conducted, note when it will be done

<h2 style="margin: 0;">Inspection and Maintenance Checklist</h2> <h3 style="margin: 0;">SAND FILTER</h3>	Property Address _____
	Property Owner _____
	Treatment Measure No. _____ Inspection Date _____
	Inspector(s) _____
	Type of Inspection:
	<input type="checkbox"/> Monthly <input type="checkbox"/> Pre-wet season <input type="checkbox"/> Post-wet season _____ <input type="checkbox"/> After heavy runoff <input type="checkbox"/> Other: _____

Defect	Conditions when maintenance is needed	Maintenance needed?	Comments ^a	Results expected when maintenance is performed
1. Standing water	When water stands over the sand filter media between storms and does not drain within 24 hours after rainfall.			There should be no areas of standing water after inflow has ceased. Any of the following could apply: sediment or trash blockages removed, filter media surface scarified, underdrains flushed, media replaced.
2. Trash and debris	Trash and debris accumulated in the sand filter and around the inlet and outlet.			Trash and debris removed from filter and disposed of properly.
3. Sediment	Evidence of accumulated sediment in the sand filter.			Material removed so that there is no clogging or blockage. Material is disposed of properly.
4. Erosion	Channels have formed around inlets, there are areas of bare soil, or there is other evidence of erosion.			Obstructions and sediment removed so that water flows freely and disperses throughout the sand filter media. Obstructions and sediment are disposed of properly.
5. Inlet/outlet	Sediment or debris accumulations.			Inlet/outlet is clear of sediment and debris and allows water to flow freely.
6. Miscellaneous	Any condition not covered above that needs attention for the sand filter to function as designed.			The design specifications are met.

^a Describe the maintenance completed; if the needed maintenance was not conducted, note when it will be done

<h2 style="margin: 0;">Inspection and Maintenance Checklist</h2> <h3 style="margin: 0;">STORMWATER WETLAND</h3>	Property Address _____
	Property Owner _____
	Treatment Measure No. _____ Inspection Date _____
	Inspector(s) _____
	Type of Inspection:
	<input type="checkbox"/> Monthly <input type="checkbox"/> Pre-wet season <input type="checkbox"/> Post-wet season _____ <input type="checkbox"/> After heavy runoff _____ <input type="checkbox"/> Other: _____

Defect	Conditions when maintenance is needed	Maintenance needed?	Comments ^a	Results expected when maintenance is performed
1. Sediment	Evidence of accumulated sediment in the forebay or wetland body.			Accumulated sediment is excavated and disposed of properly.
2. Erosion	Evidence of erosion or sloughing on embankment.			Eroded areas filled with suitable material and vegetation established.
3. Vegetation	Embankment vegetation is dead, diseased, or overgrown; trees or shrubbery are growing on the embankment; there are areas of unwanted or inappropriate vegetation. There are visible dead plants or extensive bare areas in the wetland area.			Vegetation reestablished, trees or shrubs removed from the embankment and replaced with grass; embankment vegetation is mowed, invasive vegetation removed. Dead or missing wetland plants replaced with appropriate species.
4. Clogged orifice	Debris or vegetation is restricting flow through the orifice.			Debris is removed from orifice to allow desired drawdown.
5. Clogged riser or bypass structure	Debris or vegetation is impeding flow.			Debris is removed from the riser; consider trash rack installation.
6. Riser, barrel, or embankment failure	Separation of structural components.			Professional Engineer should conduct analysis of structural condition and recommend repairs.
7. Low water level	Low-level release valve is leaking or liner has failed.			Low-level release valve replaced or repaired; liner repaired.
8. Outfall	Outfall exhibits erosion and scour.			Scoured areas repaired.

^a Describe the maintenance completed; if the needed maintenance was not conducted, note when it will be done.

<h2 style="margin: 0;">Inspection and Maintenance Checklist</h2> <h3 style="margin: 0;">CISTERN</h3>	Property Address _____
	Property Owner _____
	Treatment Measure No. _____ Inspection Date _____
	Inspector(s) _____
	Type of Inspection:
	<input type="checkbox"/> Monthly <input type="checkbox"/> Pre-wet season <input type="checkbox"/> Post-wet season _____ <input type="checkbox"/> After heavy runoff <input type="checkbox"/> Other: _____

Defect	Conditions when maintenance is needed	Maintenance needed?	Comments ^a	Results expected when maintenance is performed
1. Low flow	Gutters are full of debris and overflowing.			Gutters should be clear and free-flowing when gutters are cleaned and gutter guards or screens are installed.
2. Inlet	Filters are clogged or full.			Filters are clean and free of trash and debris.
3. First flush diverter	First flush filter is full or clogged causing permanent flow to the cistern.			First flush is diverted away from the cistern when the first flush diverter valve is removed and cleaned.
4. Cistern does not drain within 48 hours	Outlet is clogged.			Cistern completely drains in less than 48 hours.
5. Cistern drains in less than 24 hours	Cistern leaks or outlet allows excessive flows.			Cistern drains in 24 to 48 hours.
6. Miscellaneous	Any condition not covered above that needs attention for the cistern to function as designed.			The design specifications are met.

^a Describe the maintenance completed; if the needed maintenance was not conducted, note when it will be done.

<h2 style="margin: 0;">Inspection and Maintenance Checklist</h2> <h3 style="margin: 0;">EXTENDED DETENTION BASIN (EDB)</h3>	Property Address _____
	Property Owner _____
	Treatment Measure No. _____ Inspection Date _____
	Inspector(s) _____
	Type of Inspection: <input type="checkbox"/> Monthly <input type="checkbox"/> Pre-wet season <input type="checkbox"/> Post-wet season _____ <input type="checkbox"/> After heavy runoff <input type="checkbox"/> Other: _____

Defect	Conditions when maintenance is needed	Maintenance needed?	Comments ^a	Results expected when maintenance is performed
1. Clogged or non-functioning forebay	Internal erosion or excessive sediment, trash debris accumulation			Check for sediment accumulation to ensure that forebay capacity is as designed. Remove any accumulated sediment or debris.
2. Damaged structures	Cracked, eroded, or broken structural components			Repair pond inlets, outlets, forebays, low flow channel liners, and energy dissipaters when damage is discovered.
3. Erosion or debris following storms	Accumulation of litter and debris in basin area, debris around outlet, internal erosion			Remove debris to reduce the risk of outlet clogging and to improve facility aesthetics. Stabilize erosion.
4. Mowing	Overgrown vegetation on embankment or adjacent areas.			Frequency depends on location and desired aesthetic appeal.
5. Embankment Erosion	Eroded or scoured areas due to flow channelization or high flows on the embankment.			Repair eroded areas and revegetate.
6. Vegetation	Dead plants; Woody growth on embankments			Within the first year, 10% of plants can die. Survival rates increase with time. Remove trees that encroach embankment toe, top, and buffer area.
7. Vegetation death	If rain is insufficient, plants should be watered, especially during establishment period.			Once established, plants should be able to withstand dry periods, except in extreme drought.
8. Nuisance control	Animals, feces, or burrows evident in or around EDB; Excessive mosquitos; Odor			Employ qualified wildlife management professionals if needed. Remove stagnant or standing water that create odor and mosquito habitat.
9. Fertilization	Upon planting			One-time spot fertilization for first year vegetation.

^a Describe the maintenance completed; if the needed maintenance was not conducted, note when it will be done

<h2 style="margin: 0;">Inspection and Maintenance Checklist</h2> <h3 style="margin: 0;">VEGETATED FILTER STRIP</h3>	Property Address _____
	Property Owner _____
	Treatment Measure No. _____ Inspection Date _____
	Inspector(s) _____
	Type of Inspection: <input type="checkbox"/> Monthly <input type="checkbox"/> Pre-wet season <input type="checkbox"/> Post-wet season _____ <input type="checkbox"/> After heavy runoff <input type="checkbox"/> Other: _____

Defect	Conditions when maintenance is needed	Maintenance needed?	Comments ^a	Results expected when maintenance is performed
1. Sediment	Sediment depth exceeds 2 inches or covers vegetation.			Sediment deposits removed and surface re-leveled to maintain sheet flow over the filter strip.
2. Erosion	Eroded or scoured areas due to flow channelization or high flows.			No erosion or scouring evident. For ruts or bare areas less than 12 inches wide, damaged areas repaired by filling with crushed gravel. Over time the grass will start to cover the rock.
3. Trash and debris	Trash and debris accumulated on the filter strip.			Trash and debris removed from filter strip and flow spreading devices.
4. Visual contaminants and pollution	Any visual evidence of oil, gasoline contaminants, or other pollutants.			No visual contaminants or pollutants present.
5. Vegetation	When grass becomes excessively tall (greater than 10 inches). Evidence of nuisance weeds and other unwanted vegetation. Vegetation seems crowded or overgrown.			Grass mowed to a height of 2–5 inches and clippings removed. Nuisance vegetation controlled such that flow is not impeded using Integrated Pest Management (IPM) techniques if applicable. For more information, see http://www.ipm.ucdavis.edu . Minor vegetation removal and thinning. Mowing berms and surroundings. Facility looks well kept.
6. Flow spreader	Flow spreader uneven or clogged so that flows are not uniformly distributed through the entire filter width.			No visual erosion in the filter strip or ponding behind the flow spreader.

^a Describe the maintenance completed; if the needed maintenance was not conducted, note when it will be done

<h2 style="margin: 0;">Inspection and Maintenance Checklist</h2> <h3 style="margin: 0;">VEGETATED SWALE</h3>	Property Address _____
	Property Owner _____
	Treatment Measure No. _____ Inspection Date _____
	Inspector(s) _____
	Type of Inspection: <input type="checkbox"/> Monthly <input type="checkbox"/> Pre-wet season <input type="checkbox"/> Post-wet season _____ <input type="checkbox"/> After heavy runoff <input type="checkbox"/> Other: _____

Defect	Conditions when maintenance is needed	Maintenance needed?	Comments ^a	Results expected when maintenance is performed
1. Standing water	When water stands in the swale between storms and does not drain freely.			There should be no areas of standing water after inflow has ceased. Outlet structures and underdrain (if installed) should drain freely.
2. Trash and debris	Trash and debris that exceeds 5 cubic feet per 1,000 square feet (one standard garbage can).			Trash and debris are removed from the swale.
3. Visual contaminants and pollution	Visual evidence of oil, gasoline, contaminants, or other pollutants.			No visual evidence of contaminants or pollutants present.
4. Sediment	Sediment depth exceeds 2 inches or covers vegetation.			Sediment deposits removed without significant disturbance of the vegetation. Swale is level from side to side and drains freely toward outlet.
5. Erosion	Eroded or scoured areas due to flow channelization or high flows.			No erosion or scouring in swale bottom. For ruts or bare areas less than 12 inches wide, damaged areas repaired by filling with crushed gravel. Over time the grass will start to cover the rock.
6. Vegetation	Grass is sparse or bare or eroded patches occur in more than 10% of the swale bottom.			Vegetation coverage is in more than 90% of the swale bottom. Poorly vegetated areas of the swale bottom are re-planted with plugs of grass from the upper slope and reseeded in locations where plugs were taken. Plugs are planted in the swale bottom with no gaps, or reseeded into loosened, fertile soil.

	Grass is excessively tall (greater than 10 inches) or nuisance weeds and other vegetation start to take over.			Vegetation trimmed or mowed, and nuisance vegetation removed so that flow is not impeded. Vegetation/grass maintained at a height of 4–6 inches (depending on landscape requirements). Grass clippings removed. Overhanging limbs and brushy vegetation on side slopes are trimmed back.
7. Inlet/outlet	Vegetation growth is poor because sunlight does not reach swale. Sediment or debris accumulations.			Inlet/outlet is clear of sediment and debris and allows water to flow freely.
8. Flow spreader	Flow spreader uneven or clogged so that flows are not uniformly distributed through entire swale width.			Spreader leveled and cleaned such that flows are distributed evenly over the entire swale width.
9. Low-flow channel overflow	Nuisance flows are ponding, swale is continually wet.			Low-flow channel media is renewed to adequately convey nuisance flows.
10. Constant baseflow	When small quantities of water continually flow through the swale, even when it has been dry for weeks, and an eroded muddy channel has formed in the swale bottom.			A low-flow pea gravel drain can be added to the length of the swale or an underdrain can be installed to prevent an eroded or muddy channel.

^a Describe the maintenance completed; if the needed maintenance was not conducted, note when it will be done

Appendix G. Cost Estimate and Regulatory Guidance

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G.1 Cost Estimates

Planning-level cost estimates were developed for each BMP type from the latest unit bid costs from the City of San Antonio (2013), TxDOT (2013), the City of Austin (2013) and estimates from local vendors. Estimates for each cost component were developed on the basis of the design standards provided in the previous sections. Costs are based on local information and recommendations compiled from local vendors. The range in cost estimates reflects the recommended ranges in the design specifications for each component. For example, a range in media depth of 2 to 4 feet results in a cost range of \$1.75 to \$3.75 per square foot. Table G-1 summarizes common cost elements associated with the planning and design of LID BMPs. Total project costs include construction costs, bonding, and mobilization that would be part of a contractor's bid.

Table G-1. Common cost considerations in LID planning and design.

Common cost elements	
Planning	10% of total project costs
Design	30% of total project costs
Mobilization	11% of total project costs
Contingency	20% of total project costs
Site Preparation	
Clearing and grubbing	\$0.24-0.50/ft ²
Asphalt removal	\$2.32/ft ²
Concrete removal	\$2.39/ft ²
Sidewalk removal	\$1.21-2.39/ft ²

The project manager must refine these numbers throughout the phases of design to prepare a more accurate project construction estimate for bidding purposes. The inclusion of various sizes of projects in the maintenance costs attempts to include those costs in which an economy of scale has been observed. The sizes selected for this analysis were:

- Large LID BMP systems = 4000 ft²
- Medium LID BMP system = 2000 ft²
- Small LID BMP system = 500 ft²

These categories are based on typically sized LID BMPs. Treatment can be provided by a system of multiple different LID BMP types depending on the configuration of the site. Detailed information on installation and maintenance costs based on the frequency and type of maintenance required are presented in Table G-2. The information is broken into three categories

- Routine maintenance (costs associated with maintenance required monthly up to every 2 years).
- Intermediate maintenance (costs associated with maintenance required every 6 to 10 years).
- Replacement maintenance (costs associated with replacement of the system; estimated as a service life of 20 years). Replacement cost is based on removing/replacing all components of a BMP that would potentially fail in 20 years but does not include relocation of a BMP.

Appendix G. Cost Estimates and Regulatory Guidance

These unit costs can be multiplied by the size of each BMP to assist in providing full lifecycle cost analyses for these LID BMPs. Additional information on the recommended maintenance intervals for each type of BMP was provided in Appendix B. Maintenance costs are based on Water Environment Federation (WERF 2009) research that documented labor and equipment usage from other LID programs across the country. Local labor and equipment operating costs were collected from TxDOT and municipalities to determine cost structures.

Appendix G. Cost Estimates and Regulatory Guidance

Table G-2. Detailed cost estimates of LID installation and maintenance by practice type.

Components/Activities	LID practice type								
	Bioretention	Bioswale	Permeable pavement	Stormwater wetlands	Planter boxes	Sand filter	Vegetated filter strip	Vegetated swale	Cisterns/rain barrels
Installation									
Excavation			\$1.10–\$2.25/ft ²		\$3.90–\$6.15/ft ²			\$0.80/ft ³	
Without underdrains	\$2.75–\$5.00/ft ²	\$2.75–\$5.00/ft ²		\$5.00–\$15.00/ft ²					
With underdrains	\$3.90–\$6.15/ft ²	\$3.90–\$6.15/ft ²				\$2.80–\$5.05/ft ²			
2 feet (min) to 3 feet						\$1.60–\$3.20/ft ²			
Fine Grading				\$0.25/ft ²				\$0.25/ft ²	
Soil Media						\$1.90–\$5.05/ft ²			
Topsoil				\$1.35/ft ²					
Recommended mix	\$2.40–\$4.75/ft ²	\$2.40–\$4.75/ft ²			\$2.40–\$4.75/ft ²				
With engineered media	\$3.40–\$6.80/ft ²	\$3.40–\$6.80/ft ²			\$3.40–\$6.80/ft ²				
Soil Media Barrier									
Geotextile	\$0.45/ft ²	\$0.45/ft ²			\$0.45/ft ²	\$0.45/ft ²			
Washed sand (2-inch layer)	\$0.20/ft ²	\$0.20/ft ²			\$0.20/ft ²	\$0.20/ft ²			
No. 8 aggregate (min 2 inches thick)	\$0.28/ft ²	\$0.28/ft ²			\$0.28/ft ²	\$0.28/ft ²			
Underdrain Pipe (includes drainage stone, assumes 5-foot spacing)	\$3.60/ft ²	\$3.60/ft ²			\$3.60/ft ²	\$3.60/ft ²			
Curb and Gutter	\$18/ft	\$18/ft			\$18/ft				

Components/Activities	LID practice type								
	Bioretention	Bioswale	Permeable pavement	Stormwater wetlands	Planter boxes	Sand filter	Vegetated filter strip	Vegetated swale	Cisterns/rain barrels
Mulch (native hardwood)	\$0.24– \$0.39/ft ²	\$0.24– \$0.39/ft ²			\$0.24–\$0.39/ft ²				
Hydraulic Restriction Layer									
Filter fabric	\$0.45/ft ²	\$0.45/ft ²		\$0.45/ft ²					
Clay	\$0.65/ft ²	\$0.65/ft ²		\$0.65/ft ²					
30-mil liner	\$0.35/ft ²	\$0.35/ft ²	\$0.35/ft ²	\$0.35/ft ²	\$0.35/ft ²	\$0.35/ft ²			
Concrete barrier	\$12.00/ft ²	\$12.00/ft ²	\$12.00/ft ²	\$12.00/ft ²	\$12.00/ft ²	\$12.00/ft ²			
Vegetation	\$0.20–\$3.50/ft ²	\$0.20–\$3.50/ft ²		\$1.25– \$3.50/ft ²	\$0.50–\$3.50/ft ²				
Sod (buffalo)							\$0.67/ft ²	\$0.67/ft ²	
Seeding							\$0.15– \$0.22/ft ²	\$0.15– \$0.22/ft ²	
Permeable Pavement Materials									
Pervious asphalt			\$2.00/ft ²						
Pervious concrete			\$6.00/ft ²						
PICP			\$3.00/ft ²						
Plastic grid pavers			\$2.50/ft ²						
Bedding Layer									
Washed sand (2-inch layer)			\$0.20/ft ²						
No. 8 aggregate (min 2 inches thick)			\$0.22/ft ²						
No. 57 stone (min 6 inches to 1 foot)			\$0.83–\$1.67/ft ²						
Tanks/Cisterns									\$0.60– \$2.25/gal

Appendix G. Cost Estimates and Regulatory Guidance

Components/Activities	LID practice type								
	Bioretention	Bioswale	Permeable pavement	Stormwater wetlands	Planter boxes	Sand filter	Vegetated filter strip	Vegetated swale	Cisterns/rain barrels
Filter									\$40.00– \$400.00
Foundation									
Gravel (assume 6-in. depth)									\$0.75/ft ²
Concrete (assume 6-in. depth)									\$13.50/ft ²
Maintenance									
Routine Maintenance (maintenance required monthly to every 2 years)									
Routine (small)	\$7.62/ft ²	\$7.62/ft ²	\$5.32/ft ²	\$0.44/ft ²	\$7.62/ft ²	\$1.87/ft ²	\$3.73/ft ²	\$3.73/ft ²	
Routine (medium)	\$1.91/ft ²	\$1.91/ft ²	\$1.33/ft ²	\$0.34/ft ²	\$1.91/ft ²	\$0.62/ft ²	\$1.40/ft ²	\$1.40/ft ²	
Routine (large)	\$1.91/ft ²	\$1.91/ft ²	\$0.67/ft ²	\$0.24/ft ²	\$1.91/ft ²	\$0.31/ft ²	\$1.01/ft ²	\$1.01/ft ²	
Intermediate Maintenance (maintenance required every 6 to 10 years)									
Intermediate (small)	\$5.62/ft ²	\$5.62/ft ²	\$3.71/ft ²	\$1.47/ft ²	\$5.62/ft ²	\$2.61/ft ²			
Intermediate (medium)	\$2.94/ft ²	\$2.94/ft ²	\$1.85/ft ²	\$1.41/ft ²	\$2.94/ft ²	\$1.36/ft ²			
Intermediate (large)	\$2.50/ft ²	\$2.50/ft ²	\$1.85/ft ²	\$1.40/ft ²	\$2.50/ft ²	\$1.05/ft ²			
Replacement (service life of 20 years)									
Replacement (small)	\$10.52/ft ²	\$10.52/ft ²	\$6.50– \$9.50/ft ²	\$8.19/ft ²	\$10.52/ft ²	\$6.46/ft ²	\$4.17/ft ²	\$4.17/ft ²	
Replacement (medium)	\$10.17/ft ²	\$10.17/ft ²	\$6.50– \$9.50/ft ²	\$6.43/ft ²	\$10.17/ft ²	\$5.21/ft ²	\$2.33/ft ²	\$2.33/ft ²	
Replacement (large)	\$10.11/ft ²	\$10.11/ft ²	\$6.50– \$9.50/ft ²	\$5.99/ft ²	\$10.11/ft ²	\$4.90/ft ²	\$2.02/ft ²	\$2.02/ft ²	

Note: Small System = 500 ft²; Medium System = 2000 ft²; Large System = 4000 ft²

G.2 Regulatory

The general regulatory guidance given in Chapter 2 is broadened in Appendix G to cover each county and municipality in the San Antonio River Basin (SARB). This appendix serves as a point of reference for designers to research and review the master plan, land use, land development, environmental, stormwater, and utility regulations that define how LID is currently (2013) regulated within each jurisdiction. The designer should meet with the development review staff in the particular city or county of interest prior to beginning site design. The regulations are grouped by county and then further subdivided by municipality.

G.3 Bexar County

Bexar County is comprised of 21 cities with multiple unincorporated areas or Extraterritorial Jurisdictions (ETJs).

G.3.1 Bexar County Regulations

Bexar County is responsible for enforcing development and construction standards within unincorporated areas and ETJs of the member cities. Bexar County has an interlocal agreement with the City of San Antonio to apply the City's development regulations within the ETJ.

G.3.2 City of San Antonio Unified Development Code

The City of San Antonio regulates public infrastructure and land development through the Unified Development Code (UDC), which also applies to much of the surrounding ETJs. In the 2010 revision to the UDC, the timeline for regularly scheduled revisions was changed from every two years to every five years. The UDC includes a voluntary section to provide site design flexibility, development incentives, and strategies to implement LID and Natural Channel Design protocols (Section 35-210). The UDC is divided into eight major articles; however, only the articles that most affect use of LID or stormwater management are discussed below.

G.3.2.1 Article III – Zoning

Local zoning regulations define base uses (commercial, residential, etc.) as well as lot sizes, building setbacks, and individual lot open space. LID approaches can employ a number of flexible zoning options to meet the environmental objectives of a site while allowing for the most efficient use of property. The use of these options provides added environmental sensitivity to the zoning and subdivision process over and above what conventional zoning can achieve. Alternative zoning options, some of which are already used in San Antonio, include overlay districts, performance zoning, incentive zoning, impervious overlay zoning, and watershed-based zoning to allow for the introduction of innovative development, site layout, and design techniques.

G.3.2.2 Article V – Development

The development standards section provides most of the regulations covering infrastructure and land development in San Antonio and Bexar County. The sections below discuss the specific codes relevant to LID.

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G.3.2.2.1 Parkland Dedication Requirements 35-503

Dedicated park space or payment of a fee in lieu of (FILO) parkland is required for all new residential development. Preservation of native vegetation is encouraged by the tree preservation ordinance, but open space or constructed features are generally preferred. Detention areas are allowed to meet up to 50% of the park dedication requirement if they drain within 24 hours. Preserved floodplain and riparian areas can count toward park space but no specific stormwater management goals are required.

G.3.2.2.2 Stormwater Management 35-504

The City of San Antonio gives developers the option of providing onsite detention to return post-development peak flows to pre-development conditions or paying a FILO detention. The 5-, 25- and 100-year storms are analyzed for each site's Stormwater Management Plan (SWMP) submittal. The standard of care requires assessing impacts to habitable structures or public roads within 2,000 feet downstream of a site. Typically, San Antonio uses streets for drainage conveyance. Section 35-504 (g) from the UDC discusses allowing the 25-year storm to flow in the road as long as one lane in each direction remains passable. This design approach makes it important to encourage LID water quantity and quality mitigation features within the street right-of-way.

No specific permanent BMPs are required to mitigate high frequency flow increase, sediment discharge or other water quality components of concern. However, Section 35-504 (b) (8) states:

The City of San Antonio (COSA) encourages the installation of low impact development (LID) features such as engineered swales, engineered infiltration storm sewer systems, bioretention, and engineered wetlands. For all developments proposed within the COSA jurisdictional boundaries, these features may be considered on-site detention features to the extent that they reduce the stormwater runoff expected downstream as a result of such developments. It shall be the developer's responsibility to demonstrate that said LID features provide such benefit. Credit toward Regional Stormwater Management Participation fees will be considered and approved on a case by case basis by the department of public works.

This section from the UDC along with the River Improvement Overlay design language ([G.3.2.3.1](#)) is an important first step in encouraging LID implementation.

G.3.2.2.3 Transportation and Street Designs 35-506

The street design criteria include standards specific to grade, pavement composition, drainage, rights-of-way, sidewalks, medians, and such. Pavement width and design speed are specified for each street category based on the type of use and connectivity within the transportation network. No specific stormwater quality requirements are included. All street classifications can incorporate LID measures that vary depending on use, design speed, and character of the neighborhood and that are compatible with complete streets policies, such as the City of San Antonio's. These policies promote safe and convenient access and travel for all users including pedestrians, bicyclists, transit riders, and people of all abilities. The City of San Antonio's policy specifically encourages LID to help manage stormwater runoff.

G.3.2.2.4 Landscaping 35-511

The City of San Antonio has mandatory landscaping requirements for new development, redevelopment, and additions (including new parking lots). A landscaping plan is generally

required to define how the site will achieve conformance with the ordinance. However, if all landscape buffer, landscape and tree preservation requirements have been met by the utilization of existing trees and vegetation, the plan only has to show the layout of the preservation areas. This approach is consistent with LID principles that seek to preserve natural areas. If new landscape areas are required for a site, LID BMPs that utilize vegetation (bioretention, bioswales, and planter boxes) can be used to meet the landscaping ordinance. For example, bioretention areas within parking lots can be planted with trees to meet parking lot shading requirements.

G.3.2.2.5 Tree Preservation

The Tree Preservation ordinance is primarily designed to preserve or enhance tree canopy throughout San Antonio and its ETJ. There are existing incentives in the UDC for the implementation of LID features since the canopy requirement can be reduced by lowering the impervious cover below conventional development. One incentive for LID practices is that a “canopy cover credit of one and one-half (1.5) times the existing canopy cover of trees [is] provided for areas where tree preservation is maintained in conjunction with LID practices such as the use of structured soils including infiltration trenches, bioswales, micro-bioretention areas and where such locations receive appropriate amounts of stormwater runoff” (Sec. 35-523 (i) (13)).

G.3.2.3 Article VI – Historic Preservation and Urban Design

G.3.2.3.1 River Improvement Overlay Districts (RIO) 35-670

During the 2010-11 Rio District amendment process, reference to LID features was added under Sec. 35-670(b)(3). Sec. 35-670 encourages LID features in all six RIO districts and allows them to “be considered on-site detention features to the extent that they reduce the stormwater runoff expected downstream as a result of such developments.” However, Sec.35- 673(7) requires roof drainage into storm drains or other stormwater detention facilities and these cannot discharge above the normal water level of the river.

G.3.3 City of San Antonio Master Plan

The City of San Antonio’s Comprehensive Master Plan and associated sector plans provide guidance to regulators and developers about desired uses for specific areas of the City and ETJ. For example, the City South Management Area and Heritage South Sector Plan document the desired feel and long-term redevelopment goals based on community input. Currently LID is included in the Master Plan goals as part of watershed protection but is not tied to specific criteria. Implementing LID concepts incorporates higher dwelling unit densities (e.g. clustering of houses) balanced with natural habitat preservation. LID is generally compatible with the sector plan goals, and if properly implemented with good site planning, would provide protection of cultural resources, riparian and aquatic habitat, encourage onsite stormwater controls, and protect watershed-scale hydrologic processes. In addition, LID, when incorporated with transportation networks, can be a facet of complete streets that encourage alternative modes of transportation.

G.3.4 Edwards Aquifer Recharge and Contributing Zones

The Edwards Aquifer Recharge and Contributing Zones are subject to additional regulations because of the potential for development activities to pollute the Edwards Aquifer, which is the main water supply for much of the San Antonio Region. The regulations originating from SAWS are explained below. The TCEQ regulations were discussed previously.

G.3.4.1 SAWS Aquifer Protection Ordinance

Pollution Prevention Criteria Sec. 34-925: SAWS limits maximum impervious cover percentage requirements based on land use types. The regulations become stricter within the recharge zone. For example, impervious cover may not exceed 15% for single-family residential, multi-family residential, or commercial unless it can be proved that additional impervious cover will not cause degradation.

Pollution Prevention Criteria Sec. 34-913: Buffer zones are required adjacent to streams, where 80% of trees must be preserved and the buffer zone should maintain hydraulic and water quality functions. In the code, buffer zones do not require establishment of vegetation if the area is already denuded.

G.3.4.2 SAWS Drought Restrictions

SAWS regulates outside water use during periods of low Edwards Aquifer levels and, during these periods, generally limits landscape watering to one day per week. A variance process exists for new landscaping that allows more frequent watering for up to five weeks (see <https://www.saws.org/conservation/droughtrestrictions/>). The variance only applies to new landscaping projects that meet SAWS' WaterSaver Landscape requirements. SAWS also limits the type of turf grass that builders are allowed to install in yards. LID designers should select plants based on drought resistance and be aware of the current and likely drought restrictions during planting periods. Appendix E provides further information on drought tolerant vegetation appropriate for LID implementation.

G.3.5 Endangered Species

The City of San Antonio requires submission of a Habitat Compliance Form for all projects requiring a development services permit. The Edwards Aquifer Recharge Zone and adjacent karst geologic layers (see Figure 2-2) have been identified as habitat for endangered karst invertebrates that are listed by the U.S. Fish and Wildlife Service. Similarly, the Golden-Cheeked Warbler is an endangered species that nests in the Ashe-juniper and oak woodlands in ravines and canyons found in north Bexar County. Habitat conservation and recovery plans for all species are on file with the USFWS.

G.3.6 Suburban Community Ordinances

The ordinances for the suburban communities in Bexar County do not directly address LID/GI. Alamo Heights, Castle Hills, Converse, Helotes, Kirby, Leon Valley, Live Oak, Shavano Park, and Terrell Hills regulate and/or incentivize tree preservation. Many of the communities model their regulations after City of San Antonio and/or TxDOT standards with modifications to fit their particular community. Table G-3 lists ordinances with web addresses for the jurisdictions within Bexar County.

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Table G-3. Suburban City Ordinances in Bexar County.

Agency/City Name	Document Type	Reference Location
Alamo Heights	Code of Ordinances – Including zoning, streets, parking, and subdivision standards	http://library.municode.com/index.aspx?clientId=14492&stateName=Texas
	City Codes – newly adopted changes	http://www.alamoheightstx.gov/government/government-citycodes.php
Balcones Heights	Code of Ordinances – Chapter 152	http://www.balconesheights.org/zoning_map.htm
Castle Hills	Code of Ordinances - Including zoning, streets, parking, and subdivision standards	http://www.cityofcastlehills.com/government/codes-ordinances/
	Zoning – Ordinances and Map	http://www.cityofcastlehills.com/government/zoning-planning/
Converse	Code of Ordinances - Including zoning, streets, parking, drainage, landscaping and subdivision standards.	http://library.municode.com/index.aspx?clientId=14701&stateName=Texas
Elmendorf		Contact 210-635-8210
Fair Oaks Ranch	Code of Ordinances - Including zoning, streets, parking, drainage, landscaping and subdivision standards.	http://z2.franklinlegal.net/franklin/Z2Browser2.html?showsset=fairoaksranchset
	Un-codified Ordinances	http://www.fairoaksranchtx.org/Archive.aspx?AMID=45&Type=&ADID=
Grey Forest	Ordinances – 45B - Zoning/Building	http://greyforest-tx.gov/citizen-information/ordinances/
Helotes	Ordinance – Chap 34 Environment, Chapter 78 Subdivisions, Chapter 94 Vegetation	http://www.helotes-tx.gov/index.asp?Type=B_BASIC&SEC={4C051190-DF9A-444C-AFB8-831CD2A4EAA8}
Hill Country Village	Code of Ordinances – Chapter 62 Subdivisions	http://library.municode.com/index.aspx?clientId=14034
Kirby	Code of Ordinances – Including zoning, streets, parking, drainage and subdivision standards	http://www.amlegal.com/nxt/gateway.dll/Texas/kirby/cityofkirbytexascodeofordinances?f=templates\$fn=default.htm\$3.0\$vid=amlegal:kirby_tx
Leon Valley	Code of Ordinances - Including zoning, streets, parking, drainage, landscaping and subdivision standards.	http://z2codes.franklinlegal.net/franklin/Z2Browser2.html?showset=leonvalleyset
Live Oak	Code of Ordinances - Including zoning, streets, parking, drainage, landscaping and subdivision standards.	http://library.municode.com/index.aspx?clientId=14582&stateName=Texas
Olmos Park	Code of Ordinances - Including zoning, streets, parking, drainage, landscaping and subdivision standards. Follows typical design criteria of other cities in Bexar County	http://library.municode.com/index.aspx?clientId=15097
San Antonio	Unified Development Code	http://library.municode.com/index.aspx?clientId=14228
SAWS	Aquifer Protection Ordinance	http://www.saws.org/environment/ResourceProtComp/aquifer_protection/ordinance.cfm
	Water Conservation Ordinance	http://www.saws.org/conservation/ordinance/
Schertz	Code of Ordinances – Water Conservation, Drainage Utility	http://library.municode.com/index.aspx?clientId=13783&stateName=Texas
	Comprehensive Land Use Plan – Community Vision, Land Use, Transportation, Parks, Community Enhancement, Growth Capacity – Smart Growth	http://laserfiche.schertzweb.com/Weblink7/Browse.aspx?dbid=1&startid=54103

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Agency/City Name	Document Type	Reference Location
	Unified Development Code – Zoning, Parking, Subdivisions, Drainage, Transportation, Site Design, Landscaping	http://laserfiche.schertzweb.com/Weblink7/Browse.aspx?dbid=1&startid=54103
Shavano Park	Code of Ordinances – generally mirrors COSA regulations	http://library.municode.com/index.aspx?clientId=14473
Somerset		Contact (830) 429-3639
Terrell Hills	Code of Ordinances – Chapter 13 Traffic and Streets, Chapter 14 Zoning	http://www.terrell-hills.com/thco.html
Town of Hollywood Park	Recent Ordinances	http://hollywoodpark-tx.gov/ordinance/
	Code of Ordinances – Comprehensive Ordinances, Zoning, Parking, Subdivisions, Parks, Drainage, Streets	http://library.municode.com/index.aspx?clientId=14200
Universal City	Code of Ordinances – Ch. 4-2 Planning - Subdivisions, Streets, Drainage, Parks; Ch. 4-5 Zoning –Use Table, Landscaping, Parking	http://library.municode.com/index.aspx?clientId=10332
Windcrest	Code of Ordinances - Including zoning, streets, parking, drainage and subdivision standards.	http://www.windcrest-tx.gov/?nid=453
	Walzem Road Area Revitalization Plan	http://www.windcrest-tx.gov/DocumentCenter/Home/View/461

G.4. Goliad County

Goliad County contains one incorporated city, which is the county seat Goliad. The County government regulates development in the majority of this mostly rural county.

G.4.1 Goliad County Regulations

Goliad County publishes development codes in a set of subdivision regulations available from the website at http://www.co.goliad.tx.us/default.aspx?Goliad_County/County.News. Article III defines the platting procedure as the process for subdividing land in Goliad County and includes the requirement for a pre-submittal meeting with the Precinct Commissioner and a Registered Engineer or Surveyor. Section V specifies minimum road widths of 20 feet and allow rural street cross-sections with borrow ditches to convey flow. Section VII – Drainage and Flood Control provides design guidance for stormwater runoff management for new subdivisions. Streets and drainage structures are designed for 10-yr to 25-yr storms unless all residential lots are larger than 5-acres. In that case, local and collector streets can be designed for a 5-yr storm. In all cases, the 100-year storm must be contained within the right-of-way. Drainage calculations must be based on the fully developed conditions and use commonly accepted engineering practices used within the area (Section 7.6).

G.4.2 City of Goliad Regulations

The City of Goliad publishes regulations in a code of ordinances available from the website at <https://z2.franklinlegal.net/franklin/Z2Browser2.html?showset=goliadset>. Chapter 10 – Subdivision Regulation defines the procedures for creating a subdivision with the City’s jurisdiction. A pre-application conference is necessary for new major subdivision applications with the goal of familiarizing the applicant with city requirements and for city officials to provide

guidance for preparing a preliminary plat (Sec. 10.02.006 Procedures). Design requirements for residential subdivision layouts, street widths, drainage, and sidewalks are included in Section 10.02.012 and group housing and commercial development in Section 10.02.013. No specific requirements for water quality, native vegetation preservation, tree canopy, or onsite stormwater management were noted (Accessed May 8, 2013). However, the code does provide considerable flexibility and pre-application conference provides a good opportunity to discuss implementing LID BMPs for a retrofit or new development.

G.4.2.1 Zoning

The City regulates land use through Section 14 –Zoning and provides a map of the approved uses that is available from the web address <http://www.goliadtx.net/DocumentCenter/View/565/City-of-Goliad-Zoning-Map-2010?bidId=>. The City’s website recommends coordinating with City personnel to verify zoning for individual properties. Minimum parking requirements are included in the Zoning regulations under Section 14.02.353. Parking for mixed use areas is generally required as the sum of all parking spaces required for all uses. However, the board of adjustments may reduce the total number of parking stalls for reasons such as:

- Joint uses that generate demands at different hours of the day
- Facilities served by publicly available parking capacity
- Facilities primarily served by public transportation, bicycles or pedestrians

G.5 Karnes County

Karnes County is home to three incorporated communities: Karnes City (county seat), Falls City, and Kennedy.

G.6 Wilson County

Wilson County has four incorporates cities: Floresville (county seat), La Vernia, Poth and Stockdale.

G.6.1 City of La Vernia

The City of La Vernia publishes regulations in a Code of Ordinances available at <http://library.municode.com/index.aspx?clientId=14626>. Chapter 30 – Subdivisions discusses the requirements for platting, streets, drainage, and sidewalks. Chapter 38 – Zoning cover acceptable uses, parking and landscaping. The requirements generally follow ordinances described previously for Bexar County and the San Antonio River Basin.

G.6.2 City of Floresville

The City of Floresville publishes regulations in a Code of Ordinances that can be obtained from City Hall by calling (830) 393-3105. Chapter 152: Subdivisions defines the procedures for creating a subdivision including preliminary and final platting requirements in Sections 152.20 and 152.35. Standards and specifications are detailed in Sections 152.50 through 152.61. The sections define lot sizes, street sizing and a requirement for adequate storm drainage. There is considerable flexibility within the ordinance to implement roadside and onsite BMP’s in new subdivisions.

G.6.3 City of Poth

The City of Poth publishes regulations in separate ordinances available from the website at <http://www.cityofpoth.org/blog/ordinances/>. The Subdivision Ordinance defines the procedures for creating a subdivision with the City's jurisdiction. Poth requires submittal of preliminary and final plats along with construction plans and plat fees. General requirements for residential subdivision layouts, street widths, drainage, and sidewalks are included in Section 10 and specific requirements for streets and drainage are provide in Exhibit A – Technical Specifications. Floodplain management criteria are provided in a separate Flood Damage Prevention Ordinance which includes Exhibit A - Hydrologic and Hydraulic Design Criteria as No specific requirements for water quality, native vegetation preservation, tree canopy, or onsite stormwater management were noted (Accessed May 8, 2013). However, the code does provide considerable flexibility for drainage design and street requirements and the pre-application conference provides a good opportunity to discuss implementing LID BMPs for a retrofit or new development.

G.6.4 City of Stockdale

The City of Stockdale regulates development through a Subdivision Ordinance No. 297-010801-01 that can be obtained from City Hall by calling (830) 996-3128. The ordinance defines the procedures for creating a subdivision including preliminary and final platting requirements in Sections III and IV. Section VII – General Requirements and Design Standards defines lot sizes, street sizing and design, curb and gutter, sidewalks and storm drainage. Section VII-7(a) requires storm drainage facilities when “prevention of erosion cannot be accomplished satisfactorily by surface drainage.” LID BMPs are very effective at preventing onsite erosion and channel erosion. Stockdale allows streets to carry up to the 10-year storm and storm drains must be sized for the 25-year storm. Detention is not required by the ordinance but is left to the City or City Engineer's discretion.

G.6.5 Wilson County

Wilson County government ordinances are available from the web address http://www.co.wilson.tx.us/default.aspx?Wilson_County/Ordinances. The Subdivision and Development Rules and Regulations - Article II defines the platting procedure as the process for subdividing land in Wilson County and includes the recommendation for a meeting with the Precinct Commissioner and a Registered Engineer or Surveyor. Lot density is defined based on availability of water and sewer service from centralized systems or individual onsite facilities. Article V specifies drainage requirements for roadways, channels and stream crossings with the FEMA Special Flood Hazard Area. Article VII – Road Construction and Drainage Requirements defines Right-of-Way dedication, street widths and drainage design methods.

G.7 References

- City of Austin (COA). 2013. Average Bid Prices 05-09-13 Excel Spreadsheet. <http://austintexas.gov/page/average-bid-prices>. Accessed May 2, 2013.
- COSA (City of San Antonio). 2013. Unit Price List 09-2012 PDF, <http://www.sanantonio.gov/CIMS/CurrentVendorResources/UnitPriceList.aspx>. Accessed April 30, 2013.
- TxDOT (Texas Department of Transportation). 2013 *February 2013 – April 2013 Average Low Bid Unit Price*. <http://www.txdot.gov/business/letting-bids/average-low-bid-unit-prices.html>. Accessed May 1, 2013.
- Water Environment Research Foundation (WERF). 2009. BMP and LID Whole Life Cost Models Version 2.0. SW2R08. www.werf.org.